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A REQUIREMENTS ANALYSIS OF THE 2008 MILSATCOM ARCHITECTURE

by

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As we enter the Information Age, communications connectivity and capacity will equate to operational effectiveness for Naval forces. This thesis identifies requirements shortfalls in the proposed architecture. It specifies the frequency bands where deficiencies are evident. It also proposes alternatives to fulfill or augment noted requirements shortfalls.

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A REQUIREMENTS ANALYSIS OF THE 2008 MILSATCOM ARCHITECTURE

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ABSTRACT

The U.S. Navy is different from the other armed forces in its communications requirements. Due to the lack of terrestrial connectivity possessed by other services, the Navy has become highly reliant on SATCOM for all forms of communication. This thesis presents a requirements analysis of a proposed MILSATCOM architecture. The architecture, when fielded, will form the backbone for all U.S. military satellite communications. It is expected to be operational in the year 2008. The purpose of the study is to determine if the proposed architecture meets Naval communications requirements as defined in the Emerging Requirements Data Base (ERDB). In keeping with the stated purpose, only Naval requirements were loaded for the analysis. Requirements from other services and government agencies were not considered for this study.

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LIST OF AN ACRONYMS

A/EHF	Advance Extra High Frequency
AJ	Anti-Jam
ARG	Amphibious Ready Group
ASAT	Anti-Satellite
BAH	Booz-Allen & Hamilton, Inc.
BLOS	Beyond-Line-Of-Sight
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
COMMERSAT	Commercial Satellite
CONUS	Continental United States
CVBG	Carrier Battle Group
DAMA	Demand Assigned Multiple Access
DoD	Department of Defense
DPSK	Dual Phase Shift Keying
DSCS	Defense Satellite Communications System
EC	Earth Coverage
ECCM	Electronic Counter Counter Measures
EHF	Extremely High Frequency
EMI	Electro-Magnetic Interference
ERDB	Emerging Requirements Data Base
FEDSIM	Federal Systems Integration and Management Center

FRD	Functional Requirements Document
GBS	Global Broadcast Service
HDR	High Data Rate
ICDB	Integrated Communications Data Base
IO	Indian Ocean
JTF	Joint Task Force
LAN	Local Area Network
LDR	Low Data Rate
LRC	Less than Regional Conflict
MDR	Medium Data Rate
MILSTAR	Military Satellite Communications System
MRC	Major Regional Conflict
NCC	Network Control Center
NSB	Narrow Spot Beam
NSFS	Naval Surface Fire Support
PAC	Pacific Ocean
QPSK	Quadrature Phase Shift Key
TT&C	Telemetry, Tracking and Control

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I. INTRODUCTION

A. PURPOSE

The United States maintains a fleet of communications satellites which have proved to be the backbone of U.S. military communications for the past several decades. This architecture has been sufficient to support recent military operations, but lacks the capabilities required to carry out the information intensive operations expected in the near future. The U.S. is currently developing plans to replace its aging inventory of communications satellites with a new, more robust, satellite communications architecture. This architecture is expected to meet the communications requirements of the Armed Forces, as well as other national agencies, as we enter the information age.

The constellation of satellites proposed by the Department of Defense Office of the Space Architect is a fully integrated communications architecture. It is designed to leverage the capabilities of each individual system. The architecture is optimized for support of joint operations. It will provide different levels of service, robustness and survivability throughout the Joint Command hierarchy. Each system has its own strengths and weaknesses, each of which plays a specific role in the architecture. This integrated communication system will provide a large percentage of the Command, Control, Communications, Computers and Intelligence (C4I) capabilities defined as requirements by the individual services. [Ref. 1:p.15]

The Navy is unique from the other armed forces in its communications requirements. Naval units are inherently mobile and, therefore, lack the traditional connectivity possessed by their counterparts. Due to the lack of terrestrial connectivity, the Navy has become highly

reliant on satellite communications (SATCOM) for all forms of communications. The increased use of satellite assets enhances U.S. Naval mission effectiveness. It is therefore highly important that the architecture which is to be implemented meet all Naval requirements.

The purpose of the thesis research presented in this document is to perform an independent evaluation of the performance of the proposed MILSATCOM architecture with respect to Naval requirements. As discussed in the above section, the implications of this architecture will have far reaching effects on the structure and operational effectiveness of the Navy in the 21st century.

1. Importance of MILSATCOM

MILSATCOM, with its world wide coverage and large bandwidth capability, is indispensable in today's Navy. It provides reliable and secure communications and data services to deployed units. There is no other form of communication which can take the place of satellite communications. SATCOM allows commanders at sea to maintain continual contact with their chains of command. Continual contact is becoming more important as certain parts of the globe become less stable.

2. Long Term Impact of the Architecture

The proposed MILSATCOM architecture, if implemented, will have an impact on the armed forces of the United States for years to come. At an expected cost of 65 billion dollars, this integrated communications system will take years to develop and acquire. It is expected to be in place by the year 2008. Once in place, this system will be required to fulfill

the SATCOM requirements both the Department of Defense and other national agencies. It is imperative that the system have the capacity to handle the communications needs of the future. If the system is unable to handle today's data requirements, or those in the near future, it has little prospect of being an effective system in the year 2020.

3. Factors which Impact the Architecture

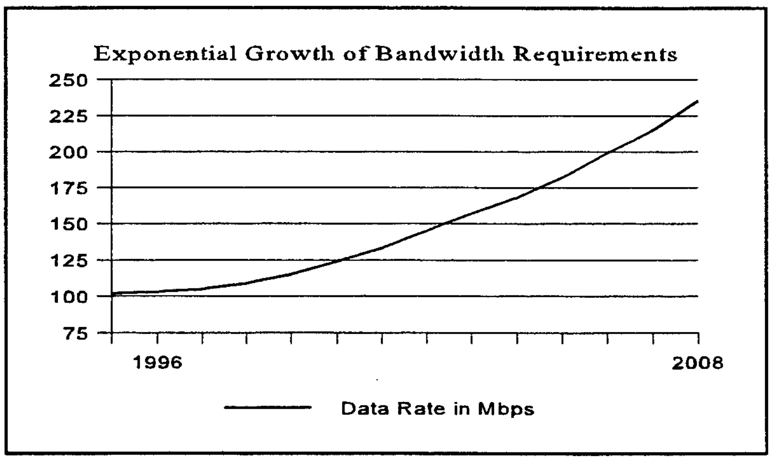


Figure 1.1. Example of Exponential Growth of Bandwidth Requirements.

There are many factors which impact the future of this architecture. The first and foremost of these is the cost. The current trend of budget cuts and shrinking defense spending does not bode well for the system. Recent arguments in Congress indicate that many feel there is little or no need for this system. Some propose contracting civilian companies to provide all future MILSATCOM. Another issue which impacts the architecture is how to predict what the data requirements will be in the future. Figure 1.1 illustrates the projected growth of data rate requirements in the near future. A distinct exponential curve is evident in the figure. This figure was created by establishing current bandwidth

requirements [Ref. 2:p. 5-18] and comparing them with anticipated requirements specified in the Emerging Requirements Data Base. Currently, these requirements appear to be growing at an exponential rate but there is no guarantee that this trend will continue. This growth has a strong impact on the cost of the system, since cost is directly related to bandwidth. If the data requirements of the future are overestimated, then the system cost will be unacceptable. If, on the other hand, future data requirements are underestimated, then the system will lose its effectiveness and will be a waste of tax-payer dollars. There are many other factors which might affect the outcome of the architecture, but cost and projected bandwidth capacity appear to be the most significant.

B. SCOPE

This document is intended to provide a broad overview of the MILSATCOM architecture and its performance. Due to the size and complexity of the project, it is impossible to delve deeply into all aspects of the system. This thesis research has centered on satisfaction of Naval requirements. Constraints are defined below which frame the problem to be analyzed.

1. General Research Questions

The intent of this research is to answer certain questions with regard to MILSATCOM. The thesis effort has been directed toward answering the following questions and analyzing the results:

a. *Question One*

Does the MILSATCOM architecture meet Naval communications requirements as defined in the Integrated Communications Database (ICDB) and the Emerging Requirements Database (ERDB)?

b. *Question Two*

What are the specific areas noted as shortfalls if the architecture does not meet the requirements?

c. *Question Three*

Once shortfalls have been noted, what can be done to fulfill them? This research has considered both proven and emerging technologies which have the potential to provide augmentation for systems with shortfalls. This section will identify specific system alternatives and provide the shortfalls which they are intended to address.

2. Limitations of Study

Specific limitations of the study must be clearly defined in order to properly frame the investigation. The analysis distinguishes among the roles of the terminal segment, budget, force structure and dependency/interoperability with commercial satellite systems.

a. *Terminal Segment*

The terminal segment of any SATCOM system plays a key role in the architecture. The terminal segment determines how 'user-friendly' the system will be to its operators. It can be as small as a hand held cellular phone or as large as a fixed military

communications station. The size of the terminal is determined by the mission to be performed and the frequency band in which it will operate.

Terminals are also important in terms of budget. In previous SATCOM systems the terminal segment has accounted for up to one half of the system lifecycle cost. Terminals also take many years to fully integrate into the fleet. Integration is a complex exercise which involves training users throughout the fleet, removing older system terminals and installing the new terminals. This entire process takes years and generally lags behind the deployment of the space segment. While terminals account for a large percentage of the budget and take years to implement, they will be held as a constant in this analysis. The assumption will be made that the terminals have been acquired and installed. The purpose of the analysis is to examine the performance of the space segment. Further research into terminal architecture and interoperability with existing systems could form the basis for a future in-depth research project. [Ref. 3:p. 1-3]

b. Budget

Budget plays a vital role in the system architecture. The budget, more than any other factor, determines system capabilities, numbers of spacecraft produced and design life of the satellites. The proposed budget for the MILSATCOM architecture is approximately 65 billion dollars. This cost will be spread over several years, but it is still a significant percentage of the defense appropriations budget as a whole. There is no guarantee that the full cost for the architecture will be appropriated by congress. This uncertainty casts some doubt as to what the final architecture make-up might be. For purposes of this analysis,

the assumption was made that Congress has appropriated the 65 billion dollars required to develop and deploy the architecture proposed by the DoD Space Architect.

c. *Force Structure for Analysis*

Force structure plays a vital role in a loading analysis for an architecture. A loading analysis is a computer simulation designed to approximate the communication capabilities required for a certain number of forces in a specific scenario. For purposes of the loading analysis performed on the proposed architecture, current naval force structure was used. Ten Carrier Battle Groups (CVBGs) and ten Amphibious Ready Groups (ARGs) were entered into the loading as the naval forces. These forces were deployed both at home and abroad. Each CVBG was comprised of one carrier, two cruisers, three destroyers, three frigates, three fast attack submarines and one replenishment ship. Each ARG was comprised of one large deck amphibious assault ship, one LPD, one LSD, two destroyers, one frigate. Both the CVBGs and ARGs also included their associated air wings and staffs. This force structure will probably be untenable by the time the proposed architecture is in place due to the rate of ship decommissionings compared to new construction efforts. It does, however, provide a good baseline to determine the total capacity of the system. This capacity can then be compared to anticipated requirements found in the ICDB and the ERDB.

d. *Dependence/Interoperability with Commercial Satellites*

The Navy currently employs commercial satellites (COMMERSAT) to fulfill requirements which are not being met by today's MILSATCOM system. There is no reason to suspect that this practice will not be carried out in the future. In some instances,

COMMERSAT provides effective, cost efficient communications where none existed before. This allows the Navy to leverage commercial systems in order to provide service for which there is no military capability available. This type of service is extremely valuable in providing surge capacity. The military, in all likelihood, will become more dependent on this form of communication in the case of regional crisis. In the future, military terminals and systems will likely become more interoperable with commercial systems to facilitate communications.

For the purposes of this analysis, COMMERSAT capabilities associated with DoD system augmentation were omitted. The analysis examines the capabilities of the MILSATCOM system alone. The communications loadings were made independent of commercial system capabilities. The requirement was to establish the limitations of the architecture without augmentation. This allowed identification of specific areas of weakness in the architecture. Once these areas were identified, analysis was performed to identify the most cost effective means of fulfilling the shortfalls. In some instances a space based system might not be the most efficient means of communications.

C. METHODOLOGY

This thesis was created by researching current MILSATCOM systems, analyzing the loading analysis, and investigating current and emerging communications technologies.

1. Data Collection Technique

Data Collection was done by gathering information from numerous publications and databases. This was used in addition to the architecture loading analysis performed by Booz-Allen & Hamilton Inc., for Naval Space Command. Once the analysis was complete, it was

compiled into Federal Systems Integration and Management Center (FEDSIM) document 85072NAD-09 [Ref. 4]. The combination of published material and raw loading data formed the basis for this thesis.

2. Data Analysis Technique

Data analysis was completed by studying the results of the system loading performed on the 2008 MILSATCOM architecture. Areas of weakness were noted and then analyzed so as to provide possible alternatives to alleviate the bandwidth shortfalls. Current systems and those under development were examined for their possible value.

D. ORGANIZATION OF THESIS

Chapter I provides the reader an understanding of the purpose and scope of the thesis. It describes the methodology used for the data collection and analysis of the material used in the study. It then goes on to provide a large background section. The intention for chapter one is to provide a reader, who might not have a space systems related background, the information necessary to fully comprehend the analysis in the body of the thesis.

Chapter II provides the implications of the current MILSATCOM system on the fleet. By understanding the impact of the current system, it is easier to assess the value provided by its successor. This chapter discusses naval force deployment and the organization of the units. It also describes the individual systems in the current MILSATCOM system. Then it discusses some of the operational and quality-of-life implications brought about by improved SATCOM capabilities.

Chapter III provides insight into envisioned MILSATCOM requirements. It begins

by reviewing both the ICDB and the ERDB and their contents. Then it discusses Naval SATCOM functional requirements and some of the challenges for the future. This chapter concludes by examining some of the vulnerability issues which face SATCOM today.

Chapter IV describes the system loading methodology. It begins by listing the assumptions made in the generation of the scenario. It also addresses the force structure used to generate the SATCOM traffic. Once the background has been laid, it then outlines the loading scenario build-up. Beginning in a peace-time situation, the program escalates military activity to the point of one Major Regional Conflict (MRC) and four Lesser Regional Conflicts (LRCs). Loading analysis data is gathered at specific intervals during the build-up.

Chapter V is an analysis of the loading results. This is where specific shortfalls in the architecture are discussed. Tools used to conduct the loading are identified. The analysis examines shortfalls at each of the steps in the scenario build-up. This leads directly into chapter six. Chapter VI consists of conclusions and recommendations from this study.

E. BACKGROUND

Before beginning an analysis of the architecture as a whole, it is important to define certain terminology as it applies to satellite communications. Familiarity with the components that make up a communications system and how they interact is required. It also is necessary to understand the laws of physics which govern satellite operations. The remainder of this chapter is dedicated to building the baseline knowledge necessary to fully comprehend the analysis. The intent in this background section is to develop a pool of information which allows an individual without space systems experience to fully comprehend the later chapters

in this document.

1. Definitions

For the purpose of this analysis it is necessary to build certain working definitions of terminology which directly relate to the subject at hand.

a. Space Segment

The space segment consists of the satellite or spacecraft with its various support and payload subsystems. The terms satellite and spacecraft are often used interchangeably, but the term spacecraft is more frequently seen in military documents. In the case of a MILSATCOM system, the payload is generally the communications subsystem. [Ref. 5:p. 3-1]

b. Control Segment

The control segment consists of three major operations. Control of the spacecraft is one of these. Spacecraft control is the process by which operators monitor and maintain vehicle attitude control, station keeping, maneuvering and ephemeris data generation. A broad term used to describe the majority of these tasks is Telemetry, Tracking and Control (TT&C). The second operation is payload control which consists of antenna pointing and transponder adjustments. It is concerned with the monitoring, upkeep and employment of the payload. The Network control operation is concerned with the spectrum management of the frequencies assigned to the system.

c. Terminal Segment

The terminal segment is a reference to the complex of terrestrial (land-, sea-, or air-based) user hardware, software, and connectivity for accessing communications over the space segment. It is sometimes called the earth terminal segment or the terrestrial segment.[Ref. 5:p. 3-2]

d. Wideband

Wideband data rates are considered to be greater than 64 kbps. Wideband services are used to support medium and high capacity SATCOM requirements.

e. Narrowband

Narrowband data rates are defined as equal to or less than 64 kbps. These services are used to support low capacity SATCOM requirements.

f. Mobile

Mobile SATCOM is defined differently by each service. The Army and Air Force designate a system as mobile if it can be air lifted into an area, set up and then operated as designed This definition is inadequate for Naval applications. For Naval purposes, a mobile system will be defined as a system which can be operated onboard a ship while conducting normal operations.

g. Terminals

Terminals are a combination of hardware and software which allow access to satellite communication services. This is the segment where the user interacts with the

system.

h. Networks

Networks consist of a complex of common hardware and software through which data is transmitted. A network can be classified as either one of two topologies. The first of these topologies to be considered is point-to-point communication. A point-to-point network is analogous to a telephone system in which there is one caller and one receiver. The second topology is the netted network or netted circuit. On a netted network, many entities have access to the medium and wait for the appropriate moment to enter the net. Netted networks make up the majority of the military's communications networks. They work to decrease required bandwidth and ensure all units maintain full situational awareness. Point-to-point networks require more bandwidth to carry the same amount of traffic as the netted circuits. Their utility is in the privacy inherent to this form of communications.

i. Low Data Rate (LDR)

Some communications documents speak in terms of data rates rather than wide and narrow band. Data rates identify the specific baud rate realized by an operational system. Low Data Rate is defined as any transmission which is less than or equal to 9.6 Kbps.

j. Medium Data Rate (MDR)

Medium Data Rate is defined as any transmission greater than 9.6 Kbps, up to and including 1.544 Mbps.

k. High Data Rate (HDR)

High Data Rate is defined as any transmission over 1.544 Mbps.

l. Worldwide Coverage

Worldwide coverage, for the purposes of this analysis, is coverage around the circumference of the Earth (360 degrees longitude) and to 70 degrees North or South latitude.

m. Global Coverage

Global coverage is coverage of the entire globe. It is different from worldwide coverage in that global coverage includes the polar regions.

2. General Orbital Mechanics

Satellites are bodies which orbit the Earth. Their motion is a result of the gravitational pull of the Earth's mass. A satellite's orbit can differ depending upon a number of parameters. The first is the altitude of the orbit. The lower a satellite is , the faster it will travel around the Earth. A satellite which is at an altitude of two hundred kilometers will complete one orbit in approximately ninety minutes. A satellite which is in geosynchronous orbit (42,164 km) will complete one orbit every 24 hours. Other parameters such as eccentricity and inclination will affect a satellite's period and the coverage it provides. Figure 1.2 provides an illustration of the general orbital regimes used by spacecraft.

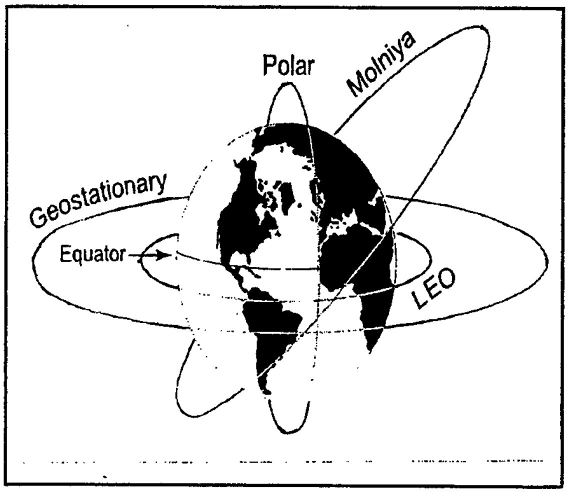


Figure 1.2. An illustration of general orbits. [Ref. 6:p. 6]

The following are definitions of general orbital regimes:

a. Low Earth Orbit (LEO)

A satellite in Low Earth Orbit will have an apogee of no greater than 1,000 km. The Van-Allen radiation belts begin at approximately 1,000 km and are used as the defining point for the upper limit of LEO orbits. LEO satellites travel extremely fast due to their low altitudes. A satellite in a 500 km LEO orbit travels at 7.6 kilometers per second. In comparison, a GEO spacecraft with an altitude of 35786 km travels at 3.1 kilometers per second. Because of their low altitudes, LEO spacecraft experience greater atmospheric drag forces than MEO or GEO satellites. Due to the drag effects on the spacecraft, greater amounts of fuel must be expended to maintain their proper operational orbits. This translates directly into a short life, generally 2 or 3 years.

b. Medium Earth Orbit (MEO)

Medium Earth Orbits are above the LEO upper limit, but lower than a geosynchronous orbit. "Mid-range altitudes may have coverage characteristics which make them particularly valuable for some missions. A disadvantage is the weight of the necessary radiation shielding or else reduced life, due to this region's increased radiation environment." [Ref. 7:p. 179]

c. Highly Elliptic Orbit (HEO)

Spacecraft in highly elliptic, or oval shaped, orbits traverse through both the LEO and MEO orbital regimes including the Van-Allen belts. The most common HEO orbit is known as a Molniya. A Molniya orientation with the proper perigee can provide coverage at higher latitudes. The former Soviet Union used such an orbit for communications satellites for many years. [Ref 7:p. 180] This form of orbit can provide extended coverage in the northern latitudes including the polar region. This is important to the Navy because the current inventory of U.S. communications satellites lacks polar coverage.

d. Geosynchronous Earth Orbit (GEO)

In a geosynchronous orbit, a satellite's motion is synchronized with an area of the Earth below it and centered on the equator. A satellite in this orbit will complete one revolution every 24 hours. This provides reduced tracking costs and easier orbital maintenance. At a distance of 6.6 earth radii from the earth's center, a GEO satellite has an altitude of 39,785 km above the earth's surface. A GEO satellite can be placed in any inclination. A GEO orbit is said to be inclined when the plane of the satellite's orbit is at an

angle to the plane of the Earth's equator. When the orbit is in the equatorial plane, the GEO is said to be geostationary, since it appears stationary with respect to an observer on the earth. For inclinations other than zero degrees, a geosynchronous satellite's motion and ground track will appear as a figure eight with its apex located over the equator.

3. Orbits of Existing U.S. Communications Satellites

Currently the United States maintains three regimes of satellites for military communications. All of these satellites operate in geostationary or low-inclination GEO orbits. In the past GEO has been deemed the most efficient orbit for communications purposes. It has reduced tracking and station keeping costs as its primary benefit. A lack of coverage above seventy degrees latitude is the one major constraint of the current system. The Navy has a requirement for polar coverage which is not being met with the existing MILSATCOM systems.

4. Current MILSATCOM System Applications

The current MILSATCOM architecture consists of numerous systems which are divided into categories based upon the frequency band in which they operate. The frequencies most often used are Ultra-High Frequency (UHF), Super-High Frequency (SHF), and Extremely-High Frequency (EHF). There are different models of satellites which are tuned to operate in one or more of the above frequency bands. The unique attributes of each system lend themselves to specific missions or forms of communications. It is for this reason that each of the satellite systems has specific applications with which it is associated.

a. *UHF Applications*

UHF satellites have been the workhorse of Naval tactical communications for years. It provides LDR and MDR services to both surface and airborne platforms. It is used to provide Beyond Line of Sight (BLOS) communications to lower echelon commands, aircraft, and ground forces ashore. [Ref. 8:p. 10]

b. *SHF Applications*

SHF satellites have generally provided wideband services to higher echelon command and fixed ground stations. SHF transmission is generally associated with national level defense communications. It is currently aboard larger surface platforms such as aircraft carriers and large deck amphibious assault ships. It is used for applications which require a higher data rate than UHF can provide. Due to the larger bandwidth and higher antenna gain, Defense Satellite Communication System (DSCS) satellites can transmit imagery in a fraction of the time required by a UHF spacecraft. [Ref. 8:p. 11]

c. *EHF Applications*

Extremely High Frequency bandwidth provides virtually unjammable, undetectable, secure, nuclear survivable communications for strategic and tactical users. [Ref. 8 p 13] The Navy is beginning to make use of the EHF frequency band. In the past, the Air Force has been the primary user of this technology. As more EHF systems are deployed, (via the UFO, a.k.a. UHF Follow-on, program and MILSTAR) the Navy is finding utility for this unique form of communication.

5. General Overview of Space Policy

All objects placed into orbit are subject to international space law and various pacts between the United States and other nations. It is for this reason important to examine international space law and other agreements to which the U.S. is a party, with regard to MILSATCOM.

a. International Law

International law, including space law evolves in part from treaties, including the United Nations Charter and resolutions plus organic documents of international organizations. Sovereign nations may enter into treaties and support them as long as it suits their security needs. When the treaty is no longer in that nation's best interest, they might absolve themselves of any regulations held within the document. There is no overarching court system which has absolute authority over international space issues. The International Court of the Hague is named by the United Nations to hear international legal disputes but all parties involved must agree to have the court hear the case. [Ref. 7:p. 742]

There are, at times, cases in which there are conflicts between U.S. statutory law and international space treaties. There had to be some decision made as to which statutes to follow in this situation. Current U.S. policy is that the most recent of the two documents would be the one to be followed. If a treaty, which has just been signed, violates a statues of U.S. law, and the law has been on the books for a number of years, then industry will use the statutes held within the treaty for guidance.

The current document used to define the principles of the U.S. space policy

is the Outer Space Treaty of 1967. This document lays down the basic philosophy and legal principles for outer space. The major tenets of the document are described below.

(1) All nations may explore space for scientific purposes. International cooperation is encouraged.

(2) No nation can claim objects in space or celestial bodies as the sovereign property of one nation. Space belongs to all persons.

(3) The rules in space will follow the established principles and rules of international law and the Charter of the United Nations.

(4) No nation will place nuclear weapons or any other weapons of mass destruction in orbit around the Earth, or on the Moon, or on other celestial bodies.

(5) Nations must use the Moon and other celestial bodies exclusively for 'peaceful purposes,' but they may involve military personnel in scientific research.

(6) Astronauts are envoys of mankind. So long as they conform to accepted rule of activity in space, they have a form of immunity. Therefore, we must return them to their home nation promptly, and implicitly, may not charge to rescue them.

(7) Recovered space objects must go back to the launching nation at its request and expense.

(8) Nations bear international responsibility for their activities in outer space, whether done by governmental agencies or private citizens. Thus, the United States must authorize and continuously supervise all space activities of its citizens.

(9) Launching nations are liable for damages to citizens of other nations caused by national and private launch facilities.

(10) Nations must maintain a register of their launches.

(11) Nations must conduct space activities so as to avoid harming or contaminating the environment. [Ref. 7:p. 743]

The United States attempts to gain maximum efficiency from its space based assets while following the guidelines of the international space policy. With this in mind, it is also important to remember that the U.S. allocates some of its satellite bandwidth to its allies during exercises or multi-national operations. This is done in a spirit of cooperation with our allies. The result of allocating a portion of the architectures bandwidth is less bandwidth available for American units to use.

b. National Space Policy

Our national space policy is defined by the President. It outlines the guiding principles for the national space program. This policy is created with a balance between national objectives and our national treaty commitments.

The Clinton Administration Space Policy. The Clinton Administration has expressed a great deal of interest in the National Space Program. The President has been a strong proponent of the International Space Station and the further exploration of Mars in the search for life. The Administration is aware that the scientific and technological base of the country are a large driving force in the national economy. By investing in the space program, the government can ensure the continued growth of the science and technology sector. [Ref. 9]

c. Naval Space Policy

Naval space policy is based upon the continued use of the UHF, SHF and EHF spectrum to continue to provide secure, reliable communications to fleet units around the world. SATCOM will be used to provide links to interface with various communications systems and networks both ashore and afloat. The primary focus will be toward joint interoperability.

6. General Overview of the Space Community

The U.S. military space program is comprised of numerous commands and agencies from each service and other DoD agencies. Each command has a specific function to perform in the space hierarchy. The below described entities are the primary commands both in, and

associated with, the Naval space effort.

a. DoD Space Architect

The DoD Office of the Space Architect was created in 1995 to act as a coordination center for the different military space programs. The Space Architect reports through the Air Force Acquisition Executive to the Defense Acquisition Executive (DAE) on matters of space system and architecture development and acquisition. Information transitions up the chain of command to the Office of the Deputy Under Secretary of Defense (DUSD) (Space). DUSD (Space) then provides the Office of the Secretary of Defense (OSD) with policy guidance for the development of space architectures which are consistent with National Security and National Military Strategies. [Ref. 10]

The Space Architect defines their purpose as:

> The purpose of the DoD Space Architect organization is to consolidate the responsibilities for DoD space missions and system architecture development into a single organization that shall integrate space architectures and systems, eliminate unnecessary vertical stove-piping of programs, achieve efficiencies in acquisition and future operations through program integration and thereby improve space support to military operations. [Ref. 10]

b. U.S. Space Command (USSPACECOM)

"The mission of USSPACECOM is to conduct joint operations in accordance with Unified Command Plan assigned missions: Space forces support, space force enhancement, space force applications and space force control." [Ref. 11] Space force support operations include the launch and control of satellites by the responsible service space command. Space force enhancement is characterized by employing space based assets to

provide support to deployed forces. "To meet this need, USSPACECOM has control of a fleet of satellites that provide ballistic missile warning, communications, weather and navigation, and positioning support." [Ref. 11] Space force application is directly related to ballistic missile defense and using on-orbit assets to offer limited protection against ballistic missile attacks. Space force control is analogous to sea control in that USSPACECOM wants to ensure access to space for U.S. and allied forces while denying it to any adversary.

c. *Naval Space Command (NAVSPACECOM)*

NAVSPACECOM is chartered to provide essential information needs and communications capabilities to Naval forces. To accomplish this task, NAVSPACECOM executes those missions assigned by U.S. Commander-in-Chief Space (USCINCSPACE). Naval Space Command has been assigned as the operational manager for Navy space based communications systems. These systems include the FLTSAT, LEASAT and UFO F/O satellite systems. They also act as an advocate in the Joint arena for Naval war fighting requirements. In addition to these missions, NAVSPACECOM advises and supports Naval units through training and the deployment of Space Support Teams to advise fleet units of space based capabilities and assets. [Ref. 12]

d. *Air Force Space Command (AFSPC)*

"The mission of the Air Force Space Command is to defend the United States of America through the control and exploitation of space." [Ref. 13] AFSPC accomplishes this objective mission statement by dividing the mission into four categories. These categories are similar to those of USSPACECOM: Space force support, space force control, space force

enhancement and space force application. The Air Force space hierarchy is responsible for the launch of all military satellites and controls the majority of U.S. satellites in execution of their space support mission. AFSPC, in cooperation with NAVSPACECOM, continually monitor all detectable objects in Earth orbit to support the space control mission. They also employ space assets in such mission areas as navigation, communications and ballistic missile warning to act as a force enhancement tool. AFSPC maintains a large force of over 530 intercontinental ballistic missiles which are on-alert continuously. This wing of the Air Force acts as the space force application mission. This division of mission areas makes space more reliable for the warfighter, and enhances the Air Forces ability to manage its space based assets. [Ref. 13]

e. Army Space Command (USARSPACE)

The Army Space Command provides support to the warfighter by maintaining and controlling numerous space based systems. These systems include, but are not limited to, the Army Ballistic Missile Defense/Anti-Satellite (BMD/ASAT), and DSCS Operations Centers. USARSPACE is also a proponent of several developmental programs which are designed to enhance warfighting capabilities through the use of the space environment. [Ref. 14]

f. Space and Naval Warfare Systems Command (SPAWAR)

"The Space and Naval Warfare Systems Command designs, acquires and supports systems which collect, coordinate, process, analyze and present complex information to the nation's leaders." [Ref. 15] SPAWAR is responsible for translating the needs of the

operational commanders into requirements for space system design.

g. Naval Education and Training Center (NETC)

The Naval Education and Training Center is responsible for the training of sailors throughout the fleet. It is the NETC which provides the training for space systems technicians and operators. They monitor billet manning levels and conduct the required training to ensure the Navy maintains the proper number of specialty coded personnel.

h. Theater Commander in Chiefs (CINCs)

Theater Commander-in-Chiefs are identified as the primary warfighters. CINCs are, therefore, the individuals who identify needed operational capabilities. These capabilities are translated into a Mission Need Statement (MNS) which is then used to define the requirements for a new system or systems. It is in this manner that the CINC is able to directly shape the future of the nation's military space based efforts.

7. Overview of Proposed Architecture

The proposed architecture is similar in some respects to the current MILSATCOM system. It will still be divided into groupings for each class of satellite. These satellites will be developed to operate in the primary military frequency bands: UHF, SHF and EHF. There is one major difference in the fact that the proposed architecture will have broadcast satellites which will function in the same manner as the GBS package on the last three UHF F/O. The following is a breakdown of the proposed architecture in an operational configuration. It will not take on-orbit spares into consideration.

a. UHF F/O Constellation

The operational UHF F/O constellation will consist of eight satellites. The assets will be placed over major areas of interest in groups of two. The proposed stationing would place two satellites, each in a geosynchronous orbit, over each of the following locations: The continental United States, Atlantic Ocean, Indian Ocean and the Pacific Ocean. This configuration will give worldwide coverage up to plus or minus seventy degrees. Each satellite will have the following resources: one broadcast channel, seventeen 25 kHz channels and twenty one 5 kHz channels.

b. SHF Constellation

The SHF constellation will consist of five satellites. Each of the satellites will be placed in geosynchronous orbit and they will be spread evenly around the Earth's equator. Each of the satellites will be equipped with four spot beams and the constellation will provide world wide coverage. The SHF frequency band is from 7.9 to 8.4 GHZ. The system is able to provide both medium and high data rate transmissions in this frequency band.

c. GBS Constellation

The GBS transponders will be placed on each of the five SHF satellites. The services provided will be very similar to those provided by the UHF F/O GBS transponders. By placing the GBS package on the SHF satellites, the DoD is able to ensure worldwide coverage and reduce the overall cost of the system. The UHF F/O program office has proven that it is far cheaper to integrate this package into an existing spacecraft bus than it is to develop and entire special purpose satellite system.

d. *EHF Constellation*

The EHF constellation will consist of four spacecraft deployed similarly to the UHF F/O satellites. Each of the MILSTAR spacecraft are equipped with advanced LDR and MDR payloads. The LDR payload will be outfitted with two spot beam transmit/receive antennas, one wide spot beam transmit/receive antenna and one agile transmit antenna. The MDR payload is equipped with eight steerable spot beam antennas. The combination of low and medium data rate payloads will ensure that the system is able to meet the bandwidth requirements of all users.

II. IMPLICATIONS OF CURRENT MILSATCOM ARCHITECTURE ON NAVAL FORCES

A. EMPLOYMENT OF NAVAL FORCES

Naval forces follow a strict framework of organization when they are deployed. Each force is organized in such a manner that it will be capable of meeting almost any operational situation encountered during the period which they are deployed. This is accomplished by assembling units in a consistent manner that leverages the capabilities of each individual platform or command. The organization of a force begins on the Joint level and then cascades down to individual naval units. One of the most common arrangements of naval forces is known as a carrier battle group.

1. Carrier Battle Group (CVBG)

The carrier battle group is the largest contingent of naval forces which is deployed on a regular basis. As the name implies, an aircraft carrier forms the heart of the battle group. Numerous other types of ships such as cruisers, destroyers, frigates and submarines act as screen and support units for the carrier. This arrangement of ships, aircraft and submarines constitutes a formidable force. The CVBG is able to project its power, through the use of aircraft and missiles, hundreds of miles into hostile territory and then relocate the entire battle force before the adversary has time to react. It has proven to be an effective tool in international politics and a potent deterrent in times of regional crisis.

One limitation on the capabilities of a CVBG is the availability of sufficient communication capability. The intelligence and command structures of the group require

tremendous amounts of information to plan and organize operations. This information demand can be directly translated into bandwidth requirements. The current MILSATCOM architecture is unable to provide the necessary bandwidth essential to support every aspect of CVBG operations. This is evident by the fact that the Navy leases commercial transponders to provide services which are unattainable through DoD-owned systems.

2. Peacekeeping

Peacekeeping is an evolving form of military operation which has the potential to become a form of low intensity combat. Forces deployed as peacekeepers are generally not equipped for, nor intended to be involved in, high intensity hostilities. Their job is to act as a barrier and keep distance between warring factions. As such, peacekeeping forces rely on their communications to provide a means of escape in the event that a local situation becomes violent. The availability and reliability of satellite communications could mean the difference between life and death for multi-national peacekeepers in remote areas. One example of a peacekeeping operation is the current involvement of U.S. forces in Bosnia. Forces deployed in this theater receive a higher priority for access to MILSATCOM assets due to the nature and volatility of their mission.

3. Limited Regional Conflicts (LRCs)

Limited Regional Conflicts consist of operations confined to specific geographical regions. Activities carried out by armed forces in these arenas fall short of total war. These operations are generally characterized as a military deployment to an area for political purposes which might not be of a classical military nature. Recent LRCs have been carried

out under the guise of humanitarian operations. Large numbers of troops and equipment might be required to achieve defined mission objectives in an LRC, even in the absence of armed conflict. Such operations take large amounts of communications capabilities, especially when friendly units are spread over large areas of rough terrain.

These types of operations have been growing in number since the end of the cold war. This has been caused by the fall of the Soviet Union and the creation of power vacuums or large scale human rights abuses in unstable political regions. Recent examples of LRCs have included Haiti and Somalia.

4. Major Regional Conflicts (MRCs)

Major Regional Conflicts are large scale military efforts which are located in a specific geographical region. Unlike an LRC, an MRC involves armed conflict. Large numbers of troops and equipment are required to achieve military dominance over an adversary. This infers that large amounts of communications capabilities are required to ensure proper unit coordination and prevent incidents of fratricide. In recent history, MRCs have required a coalition of forces to achieve mission objectives. These coalition forces also require communications capabilities. The U.S. has provided some of these capabilities to coalition partners in recent operations. This is very efficient for enabling communication between armed forces of different nationalities, but also usurps some of the limited SATCOM resources available to U.S. armed forces. An example of an MRC is the Persian Gulf War or Operation Desert Storm.

B. NAVAL RELIANCE ON MILSATCOM

The Navy relies on MILSATCOM to provide many user applications. The use of satellite assets enables deployed units to remain situationally aware on global events. It allows ships at sea to download the latest imagery of an area of interest. It aids in planning for strike and amphibious operations. Without MILSATCOM, commanders at sea would be unable to update their superiors to changing environments. Joint Commanders would be unable to maintain the necessary control required to direct units spread over hundreds of miles. No current technology is capable of providing the same services or capabilities as those available through satellite communications. It is for these reasons that the Navy has become reliant on MILSATCOM.

C. U.S. MILSATCOM ASSETS

The following is a list of existing U.S. MILSATCOM assets.

1. UHF Assets

UHF satellites have comprised the backbone of Naval SATCOM for the past few decades. Naval Space Command currently serves as the operational manager for UHF assets.

a. Fleet Satellite (FLTSAT)

The FLTSAT satellites are in geosynchronous orbits providing coverage between 75 degrees North and 75 degrees South latitude. They have provided 9.6 kbps service to the fleet for over 18 years. Each satellite is equipped with 22 channels and one additional wideband 500 kHz channel. Figure 2.1 provides an illustration of a FLTSAT

spacecraft. Current FLTSAT assets have exceeded their design life and are being replaced by the UHF Follow-on system.[Ref. 5:p. 4-3]

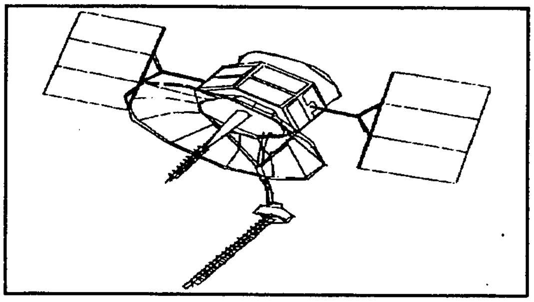


Figure 2.1. Example of FLTSAT Spacecraft. [Ref. 6:p.3-4]

b. Leased Satellite (LEASAT)

LEASAT is essentially a commercially developed system which was leased from the Hughes corporation by the U.S. Navy. It is a geosynchronous communication satellite system. This system was used as a supplement to the then existing UHF communications network. Only one LEASAT remains in use. Figure 2.2 is an illustration of a LEASAT spacecraft.

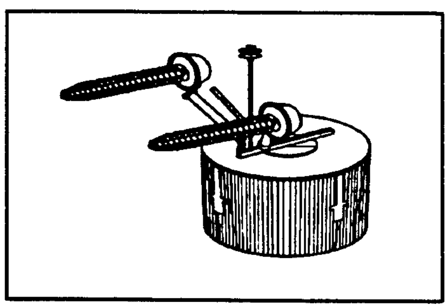


Figure 2.2. Example of a LEASAT Spacecraft. [Ref. 16:p. 11]

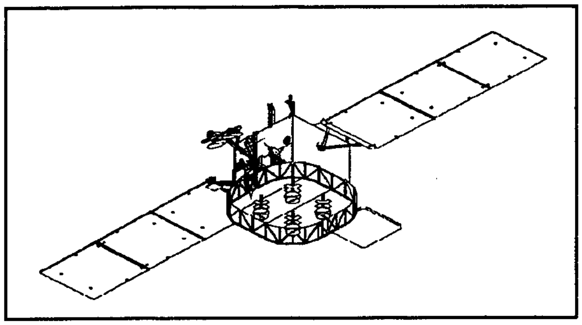


Figure 2.3. Example of a UHF Follow-On Spacecraft. [Hughes, pg. 8]

c. *UHF Follow-On System (UHF F/O)*

UHF F/O is the Naval MILSATCOM system replacing the aging FLTSAT and LEASAT spacecraft. When the constellation is complete in 1999, UHF F/O will cover the United States, the Atlantic, Pacific, and Indian Ocean areas with two satellites per area and one on-orbit spare. Figure 2.3 provides an illustration of the UHF F/O spacecraft. The spacecraft will have a channel capacity of 39 UHF channels. The first seven UHF F/O spacecraft have already been launched. The last three are undergoing upgrades to incorporate the Global Broadcast System (GBS). [Ref. 8:p. 10]

d. *Air Force Satellite Communication System (AFSATCOM)*

AFSATCOM is carried as a package on other spacecraft. The space segment consists of transponders carried on FLTSAT, LEASAT, DSCS, and other national satellites. It provides Emergency Action Message (EAM) dissemination, JCS/CINC inter-netting, force direction, and force report back. The coverage this system provides is global with the exception of the South polar region. [Ref. 8:p. 11]

2. SHF Assets

SHF assets provide the majority of wide band services to the fleet. These assets have not been fully utilized by Naval units in the past due to the terminal size required for reception. This problem is being overcome by advances in communications technology.

a. *Defense Satellite Communication System (DSCS)*

DSCS spacecraft provide worldwide, jam-resistant, secure voice and high data rate communications for command and control, crisis management, and intelligence data transfer service. The space segment consists of five DSCS III satellites in geosynchronous orbits with older versions of DSCS spacecraft acting as on-orbit spares. SHF capabilities have been incorporated into larger platforms such as carriers and large-deck amphibious ships. This was done to ensure the minimum communications requirements for command and control, intelligence, and war fighting were met. Figure 2.4 provides an example of a DSCS spacecraft. [Ref. 8:p. 12]

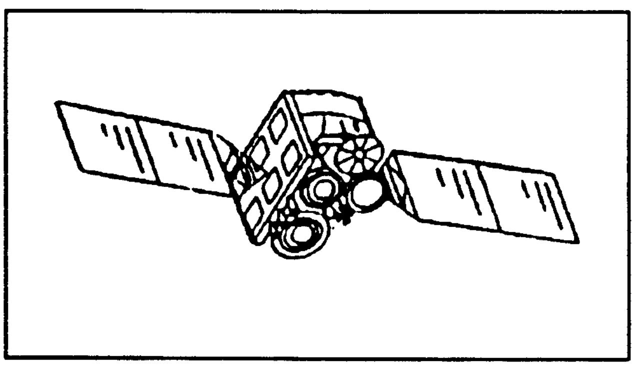


Figure 2.4. Example of a DSCS spacecraft. [Ref. 17:p. 24]

3. EHF Assets

The Extremely High Frequency bandwidth provides virtually unjammable, undetectable, secure, nuclear survivable communications for strategic and tactical users. A relatively new technology, EHF uses numerous advanced communications and signal processing techniques to perform its mission. These techniques include narrow beamwidths, interleaving, frequency hopping, cross-links, and new on-board signal processing techniques. [Ref. 8:p. 12]

a. Military Satellite Communications System (MILSTAR)

MILSTAR is an Air Force sponsored geosynchronous satellite communications program. "The system is designed to provide secure, reliable, survivable two-way worldwide communications between the command element and all segments of the force through all levels of conflict." [Ref. 5:p. 4-59] Figure 2.5 provides an illustrated example of a MILSTAR spacecraft. In the future, this system will provide both a Low Data Rate and Medium Data Rate transmission capability. MILSTAR 1 and MILSTAR 2 are the primary EHF satellites in the current inventory. These satellites are only capable of providing LDR services. They operate on an uplink frequency between 43.5 and 45.5 GHZ. Their downlink frequency lies between 20.2 and 21.2 GHz. [Ref. 5:p. 4-60]

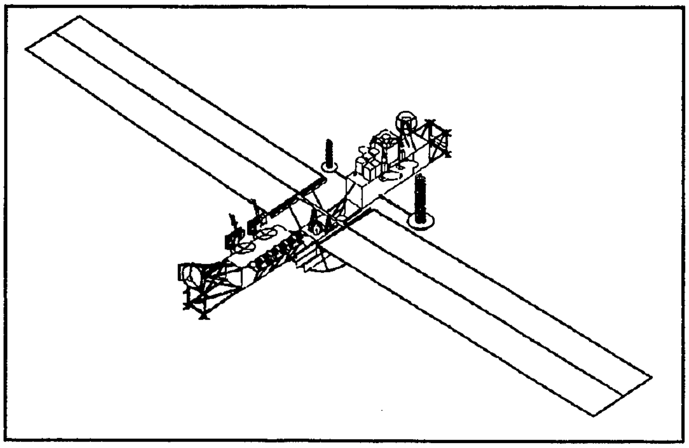


Figure 2.5. Example of a MILSTAR Spacecraft. [Ref. 16:p. 13]

b. UHF F/O

EHF payload packages were placed on UHF F/O satellite 4 and all subsequent UHF F/O spacecraft. The original package was to serve as a test-bed for MILSTAR technology. Results of the tests proved the benefits of the package warranted pursuing the placement of EHF transponders on all remaining spacecraft. This provided a cost effective means of increasing EHF connectivity throughout the fleet. Current research is ongoing to provide an EHF system with polar coverage. Figure 2.2 provides an illustration of the UHF F/O spacecraft.

4. Global Broadcast Service (GBS) Program

The Global Broadcast Service Program was approved in September 1995 in response to the need to quickly transmit high data rate files such as video and imagery to mobile users throughout the world. GBS will leverage existing commercial technologies to provide a high data rate, one-way dissemination capability. GBS will support the transmission of wide

bandwidth products to any theater at an aggregate data rate of 23 Mbps. The system will employ a method of 'smart push' in which relevant data will be broadcast to all units within the footprint. It will also include mechanisms to allow 'user pull'. This infers that a user may request data via other channels of communication and then have the data broadcast to them via GBS. A military owned GBS capability will be resident on the final three UHF F/O satellites. [Ref. 8:p. 12]

5. Commercial Service Providers

The U.S. military does not own enough satellite assets to provide all services required by the Armed Forces. After researching alternatives, the Navy decided that certain required services could best be supplied by leasing assets from commercial providers, rather than acquiring new military systems.

a. International Maritime Satellite (INMARSAT)

INMARSAT is a global consortium which uses a series of geosynchronous satellites to provide mobile satellite communication services to users on the land, in the sea or in the air. By the end of 1996, over 250 U.S. Navy ships had been fitted with INMARSAT terminals. These terminals provide voice channel surge capability and are an alternative to DoD- owned SATCOM systems. It is important to realize that INMARSAT is a commercial system and has some very significant limitations. The first is the cost of transmission. Costs have run over ten dollars per minute on an INMARSAT circuit. This cost must be paid from a ship's operational budget. A further constraint on the system is blockage and message delays during periods of peak traffic. Another handicap is the ability of an adversary to

geolocate a unit via ring-back on the user terminal. [Ref. 8:p. 14]

b. International Telecommunications Satellite (INTELSAT)

INTELSAT is a non-profit cooperative formed under the leadership of the U.S. in 1964. It is owned and operated by 120 member nations and provides service to over 180 countries and territories. It maintains a fleet of 20 GEO satellites and 2,700 earth stations around the globe. Currently the U.S. Navy leases transponders from INTELSAT to provide additional data throughput to its ships. This program is commonly referred to as 'Challenge Athena'. A single channel leased from an INTELSAT spacecraft provides 1.544 Mbps duplex communications to subscribers. This bandwidth is divided to provide different information services required by the platform. Due to the requirement for a seven foot dish antenna, and its accompanying fourteen-foot diameter radome, only aircraft carriers and certain select amphibious command ships are able to receive this service. [Ref. 8:p. 15]

D. OPERATIONAL IMPLICATIONS

The capability and capacity of a MILSATCOM architecture has direct implications on a CVBG. The capacity of the system limits the amount of intelligence or command data to which the group has access. This impacts directly on a task force commander's ability to plan and coordinate battle group operations.

1. MDR/HDR

The current trend in satellite communications is toward MDR/HDR transmission. This is a large improvement over previous capabilities. Early systems which served the fleet

were only able to provide services at 2.4 or 4.8 kbps. The transition to wideband services provides an operational commander with much greater communications capacity, and therefore, more flexibility.

2. Imagery

Imagery products consume large amounts of transmission bandwidth. A typical image can consist of tens to hundreds of mega-bytes of data. Products of this size take long periods of time to transmit on LDR and some MDR circuits. The time of transmission correlates directly to cost and operational effectiveness. Transmission time on a transponder is analogous to a long distance telephone call in that the longer the message, the higher the cost. Also, the circuit is unavailable for other applications while it is being utilized to transmit an imagery product. This situation is being resolved as modern satellites transition to higher data rates. A satellite which downlinks at 1.544 Mbps can transmit a ten mega-byte image in approximately six seconds compared to the almost sixteen minutes required for a 9.6 Kbps transmission. This increase in transmission speed will allow deployed units to receive important imagery and still have transponder free-time for other essential applications.

3. Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR)

C4ISR is very closely related to the Imagery and HDR/MDR sections discussed above. Imagery is an important Intelligence product and, therefore, imagery downloads could be considered a C4ISR function. By increasing the data rates available to Naval commanders, we will vastly increase their command and control capabilities. These increases could be

realized in the form of more command, or tactical, communication circuits. Surveillance and reconnaissance operations can require high bandwidth for imagery and other data collection. An example is the Battle Group Passive Horizon Extension System (BGPHES) which requires a multi-Mega bit channel for operation. There will also be a greater demand placed on SATCOM channels for beyond line-of-sight transmissions, as the fleet develops a greater reliance on UAVs. The envisioned information-intensive conflicts of the future demand increased C4I bandwidth for just such functions. This will allow a smaller, leaner force to operate more efficiently in the face of adversaries possessing superior numbers.

III. ENVISIONED MILSATCOM REQUIREMENTS

A. INTEGRATED COMMUNICATIONS DATA BASE (ICDB)

The Integrated Communications Database (ICDB) is a repository of communications requirements which are maintained by the Defense Information Systems Agency (DISA). "It is a comprehensive data base of communications requirements for DoD and selected non-DoD government agencies." [Ref. 18:p. 8] It is here that governmental entities define their communication needs. Requirements may be entered into the data base on either of two criteria: the type of circuit needed or bandwidth required. The data base itself contains various types of information which includes circuit protection, topology and coverage. All information held within the ICDB is focused on current communication capabilities, not those projected in the future. It identifies terrestrial and commercial SATCOM lease information as well as military SATCOM requirements data.[Ref. 18:p. 8]

DISA uses the ICDB as a management tool. It attempts to mate stated requirements for each entity represented in the data base with available assets. Agencies presenting higher national priorities will be allocated a larger percentage of resources. New additions to the data base are submitted by military CINCs and national agency heads. Once submissions have been received, they are validated by the Joint Staff and then entered as a requirement. After this procedure is complete, DISA may allocate services to fulfil the requirement.

B. EMERGING REQUIREMENTS DATA BASE (ERDB)

The Emerging Requirements Data Base (ERDB) is a tool for predicting future communications system requirements. The requirements held in the ERDB are independent

of those specified in the ICDB. The ERDB provides an estimate of specific capabilities which will be necessary to support future military operations. Systems capable of fulfilling the majority of these requirements do not yet exist. The ERDB makes assumptions as to the state of technology in the near future. This is a difficult task considering the tremendous growth rate of technology. In recent years, computer performance technology has doubled every 18 months to 2 years. This turn over in technology makes predicting communications capabilities 15 years in the future very difficult. [Ref. 18:p. 8]

There are a number of factors which must be considered when determining emerging requirements. A change in force structure is one such factor. Changes in structure demand changes in infrastructure. Today's military is becoming smaller and hopefully more efficient. As the number of ships and battalions decrease, the need for new command and control systems increases. Information superiority is becoming a key word in future military operations. Increased information requirements collates directly with increased communications capabilities.[Ref. 18:p. 8]

New technologies and weapons development create additional requirements for future systems. New 'smart weapons' and Unmanned Aerial Vehicles (UAV) require large amounts of bandwidth to create real-time video links with command centers. Current systems would be overloaded by transmitting video feeds required by these new and emerging weapons systems. Changes in doctrine, how the military is to operate or employ its weapons, can also lead to increased communications requirements. This is closely linked to force structure changes and the emergence of new weapons.[Ref. 18:p. 8]

Requirements in the ERDB are approved by the Joint Staff. Their purpose is to act

as a tool in planning and analysis for future systems. They balance communications requirements against the force structure required to counter threats predicted in the future. This data base requires continual updates due to the high technology growth rates and the volatility of predicted threats.

C. NAVAL SATCOM FUNCTIONAL REQUIREMENTS

Functional requirements are the means via which operational users are able to define their system needs to acquisition professionals. A functional requirement, specifically, is a function or operation which has been identified by the user as necessary for a system to be operationally effective. The user describes, or quantifies, the system performance characteristics which are to be achieved so that system alternatives may be competitively evaluated with respect to their effectiveness. Once functional requirements have been sufficiently defined, the acquisition community will then use these requirements to develop or acquire the most efficient, operationally effective system possible within the program funding restraints. The proper identification of functional requirements are, therefore, critical in fielding an effective operational system.

1. Impact of Proposed Systems

It has been proposed that, in the near future, information systems operating in accordance with mission demand will equate to combat efficiency.[Ref. 17:p. 12] If this vision is true, then an investment in information systems will have a dramatic impact on future combat effectiveness. Currently, there are a myriad of specific services required by fleet units which may only be provided by SATCOM. Naval units are multi-mission capable and thus

require multiple SATCOM systems to provide all required services. The Navy of the future must integrate these services into more streamlined and robust information systems. This section will examine functional requirements which have been defined for the proposed systems. [Ref. 17:p. 12]

2. Limitations of Current Systems

Current MILSATCOM systems are capable of satisfying the majority of today's communications requirements. These systems, however, lack the capacity to handle the projected bandwidth required by information intensive operations expected throughout the next 10 to 15 years. Specific limitations have been identified in each of the existing SATCOM systems. This section will describe the specific limitations noted and thus provide more insight to capabilities that must be satisfied by any follow-on systems.

a. Connectivity

According to the DoD Advanced Satellite Communications Capstone Requirements Document, [Ref. 19], connectivity is directly related to coverage and capacity. Today's legacy systems provide coverage to most areas in which the United States takes interest. While DoD-owned systems provide coverage to the majority of these areas, they do not possess the capacity necessary to provide all services to DoD users. Commercial transponders have been leased in order to provide greater capacity in regions where there is a shortfall of resources. [Ref. 19:p. 3-2]

The North Polar region is an area of vital importance to the U.S. military. Ballistic missile submarines routinely operate under the ice-cap and require communications

connectivity with their respective commands. Due to their orbital geometry, GEO communications satellites are unable to provide coverage in this region. This creates a definite communications requirement for forces serving at the pole. The only system currently providing coverage to this area is the Air Force SATCOM packages operating from other national platforms. [Ref. 19:p. 3-2]

Warfare in the future will be highly mobile. As a result, SATCOM on the move will be a key criteria for operational success. Current systems lack the capability to provide high throughput to mobile users and command structures. "Further, these systems do not efficiently use the limited spectrum available to disseminate information products to multiple users." [Ref. 19:p. 3-3] There is also a definite lack of surge capacity in the current systems. These systems will be nearing their maximum throughput to support daily operations in the future. They do not posses the capacity necessary to support surge communication requirements resulting from regional crises.

By examining connectivity limitations in the current system, it is apparent that any successful MILSATCOM system must provide greater coverage and capacity.

b. Protection

"Protection includes defensive Information Warfare (IW), Anti-Jam, covertness, nuclear survivability, resistance to physical destruction, and U.S. control of SATCOM access." [Ref. 19:p. 3-4] The MILSATCOM systems of today do not meet these benchmarks of protection.

The only current system designed specifically for nuclear survivability is the

MILSTAR constellation. Even so, the spacecraft already in orbit only provide LDR data services and would be unable to support fleet operations by themselves. "Current commercial systems lack the protection against disruption and exploitation required to support many military operations. They cannot provide the anti-scintillation and other protection from nuclear effects to support NCA requirements for command and control." [Ref. 19:p. 3-4]

Information warfare, or information operations, is a growing threat as the world enters the information age. The majority of current systems were designed prior to the explosion of information technology. As such, "neither DoD nor commercial SATCOM systems are sufficiently protected against unauthorized intrusion, monitoring, and the disclosure of sensitive information." [Ref. 19:p. 3-4]

In the future, protection of information systems will be a key to operational success. Current MILSATCOM systems do not provide adequate protection for military communications. Future systems will be required to maintain a much higher standard of communications security in order to assure friendly forces maintain information dominance.

c. Access and Control

The military has devoted a significant effort to ensure that current communications systems provide sufficient access and control for operational users. "However, there are still shortcomings in being able to provide the desired timely and dynamic configuration and reconfiguration of SATCOM resources. Support for new or changing requirements must be carefully planned and often result in disrupting existing accesses while new requirements are being loaded." [Ref. 19:p. 3-5]

U.S. armed forces employ commercial systems, in addition to DoD-owned systems, to provide some SATCOM capabilities. Commercial systems present their own dilemmas for access and control. "Military users will always have to contend with commercial users, as well as each other, for access to commercial systems. The warfighter cannot depend entirely on commercial capability for immediate surge capacity of critically needed communications anywhere in the world at unprecedented times and locations." [Ref. 19:p. 3-5]

Access and control have always been identified as critical issues by military SATCOM users. They will continue to grow in importance as we enter the information age. Today's systems do not provide timely access to users as crises evolve around the world. The current management system for adding channel requirements to SATCOM systems is too slow. It may negatively impact the operational effectiveness of units deployed in rapidly changing threat environments. Future systems should provide a more dynamic means for adding channel requirements to SATCOM systems. It should also strive to make network reconfiguration as transparent as possible to users on the network. [Ref. 19:p. 3.6]

d. Interoperability

Jointness has become a key word in modern military operations. One major premise of Joint forces is that the systems owned by each of the services should be interoperable with those of other friendly services. "The evolution of current DoD-owned SATCOM systems resulted in separate systems development, optimized for specific user communities, without sufficient interoperability between frequency bands and different classes

of users within a frequency band." [Ref. 19:p. 3-6] Loosely translated this means the communications systems from each of the services have difficulty operating with those of other services. "Furthermore, commercial systems (especially Mobile Satellite Service, [MSS]/Personal Communications Service [PCS]) have limited, if any, direct interoperability between one another without recourse to the public switched network or other intermediate communications media." [Ref. 19:p. 3-6]

To ensure greater efficiency in future Joint operations, future MILSATCOM systems should be developed by representatives from each of the services. This would ensure that requirements from each of the services were identified and incorporated into the design throughout the development of the system. Introducing requirements early in the design process can save money by eliminating the need for engineering change proposals later in the production of the spacecraft. By ensuring all high priority requirements are integrated into the system design early, military users can increase the overall effectiveness of the system while achieving a lower system acquisition cost.

e. Flexibility

"Flexibility relates to the ability of U.S. forces to use SATCOM while engaged in mobile, dynamic military operations across the full range of the spectrum of conflict." [Ref. 19:p. 3-7]

"Current DoD-owned systems do not communicate well on-the-move at needed data rates. The number of mobile terminals will greatly increase, but today's systems cannot provide the power or bandwidth to support those terminals." [Ref. 19:p. 3-7] When

the Capstone Requirements Document speaks of mobile terminals, it places the emphasis on smaller platforms such as aircraft and ground mobile units. Ships are mobile but travel at speeds slow enough to remain in a footprint for an extended period of time. They also posses enough room to house relatively large antennas which are able to supply a significant amount of bandwidth.

Today's systems do not provide enough bandwidth to support terminals which are currently fielded. "Except for upcoming DAMA initiatives, few efforts have been made to conserve bandwidth. Furthermore, today's terminals are not always optimized for the user and platform." [Ref. 19:p. 3-7] Not leveraging technology to develop further methods for frequency reuse limits the flexibility of existing systems. An effective means of frequency reuse could dramatically increase the numbers of users which could access a given system at any time.

Development of operational techniques and advanced communication technology which will increase the flexibility of future systems and will also enhance the operational effectiveness of the U.S. military. New means of frequency reuse or multiple access techniques will enable greater numbers of units to access and capitalize on MILSATCOM assets. This will provide operational commanders greater control over forces spread across large regions.

f. Quality of service

"Current DoD-owned SATCOM systems may not be able to support future more stringent quality requirements (e.g. for Asynchronous Transfer Mode). Similarly, the

current systems will probably not meet future requirements for voice recognition and intelligibility." [Ref. 19:p. 3-7] The majority of today's Naval voice SATCOM circuits operate at 2.4 kbps. There is a push, more specifically in the Marine Corps, to increase the bandwidth for some voice circuits. Marines feel that commanders can gain more insight into a situation by being able to hear the 'tension and stress' in someone's voice. In order to increase the quality of voice communication, it is required to increase the sampling rate on the voice signal. This translates directly into greater bandwidth. Assumptions for the loading analysis state that high quality voice will be at 4.8 kbps. Considering the trend toward wider bandwidth communications in commercial systems, it is plausible to assume that the requirement for high quality voice could creep up to 9.6 kbps in the near future.

> Today's SATCOM systems will not be able to adequately support tomorrow's weapons, C4ISR, and support systems' quality demands. This will lead to loss of information, delays and blockages, and denying users access to perishable, time-sensitive information. Situational awareness and dominant battle space knowledge will be diminished and weapons and C4ISR system efficiency will be greatly reduced, which will put mission success at risk. [Ref. 19:p. 3-8]

3. Required System Characteristics

DoD-owned SATCOM systems support the DoD mission areas by providing the requisite connectivity, protection, access and control, flexibility, quality of service, and interoperability. These are required system characteristics for SATCOM systems. While affordability is not listed as a specific technical system characteristic, it will be a key driver in the objective architecture solutions. [Ref. 19:p. 1-13]

CATEGORY	RATIONALE
CONNECTIVITY	>Information +C4ISR +Precision Munitions =combat Power. >Warfighter Information demands are growing in response to technology. >Connectivity cannot be a limiting factor in the application of combat power. >SATCOM = Assured warfighter connectivity when/where needed. >SATCOM supports globally dispersed land, sea, air and space operations. >SATCOM provides dynamic, multiple information transfer capabilities.
PROTECTION	>Our C4I is a prime target and a center of gravity. >Must deny adversary the ability to decapitate our C4ISR capabilities. >Nuclear deterrence remains a top DoD priority (Survivability) >Must provide anti-jam and protection from SIGINT and information warfare.
ACCESS AND CONTROL	>Available access on-demand; fundamental SATCOM need of the warfighter. >Warfighter's assured access should not be denied (within CINC/JTF priorities. >Warfighters must have control over their information and SATCOM domains. >Timely, responsive process of apportioning and reapportioning SATCOM capacity. >Appropriate force level controls access to allocated capacity. >New and unscheduled user's demands for communications can be accommodated. >Warfighter can monitor status of allocated SATCOM resources. >Allocated resources can be rapidly and dynamically reconfigured.
INTER-OPERABILITY	>Interoperability between ground, air, maritime, and SOF forces (JTF Components). >Facilitate interoperability with Allies, Coalition partners and Government Agencies. >Provide seamless Terrestrial-to-Satellite Information Transfer. >Ensure capability of Information Transfer between Commercial and Military means.
FLEXIBILITY	>Warfighters prosecute military operations across a wide spectrum of conflict. >Accommodate changing/evolving requirements, threats, technologies, capabilities. >Emphasis is on mobile operations. >A wide variety of operating frequencies is needed to support the Warfighters needs. >Must make efficient use of limited frequency spectrum. >Systems must be reliable and easy to use.
QUALITY OF SERVICE	>Performance must meet needs of supported information systems. >Information must be transferred accurately and unambiguously. >DoD SATCOM systems should be capable of degrading gracefully.

Table 3.1. Required System Characteristics. [Ref. 19:p. 1-13]

Table 3.1 provides a listing of the top level functional requirements for the SATCOM system. The requirements are divided into categories and then subdivided into more specific line items within each requirement category.

4. Challenges for the Future

There are many challenges which face the Navy as it prepares for the deployment of the next generation of MILSATCOM assets. Many of the problems which must be solved are directly related to the size, shape, and mobility of ships.

a. Mast Size for Antenna Installation

Platform mast space is one constraint for shipboard SATCOM capabilities. Each ship in the U.S. Navy maintains a multitude of antennas which service a variety of purposes. The majority of a ships antennas are housed atop the ship's mast on yardarms. This location reduces radiation hazards to personnel and does not interfere with the majority of shipboard operations. Larger platforms have more space to accommodate new and larger antennas. Aircraft carriers or large deck amphibious assault ships can carry approximately 130 topside antennas. Smaller platforms, however, are very limited in the amount of antennas they are able to carry. Destroyers and frigates may be limited to approximately 50 topside antennas. A submarine might have as few as a dozen. [Ref. 17:p. 32]

The available space for an antenna is not the only consideration when contemplating the installation of a new system. That systems support equipment must also be considered. Terminal equipment, power supplies and electronics all add weight to the ship. The weight and location of placement must be carefully considered with respect to ship stability. Studies should be undertaken to evaluate the effects of system placement on radar cross-section. Integrating a new system into an existing ship is a very complex evolution which involves many different systems throughout the entire ship and not just mast space.

b. *Mobility*

Ships are mobile by nature. They can travel hundreds of miles per day and change course at any time. Modern shipboard SATCOM systems have to be able to track the satellite they are communicating with. Shore stations do not have to do this when communicating with a GEO spacecraft. Ships, on the other hand, are constantly changing direction and experiencing movement caused by the pitch and roll of the ocean. This creates a need for a stabilized antenna which can track the satellite with which it is to communicate.

Mobility of ships can also create a problem for the spacecraft. As ships move they can travel out of a spot beam. This means that the spacecraft might have to redirect its spot beam to provide continual coverage for a battle group at sea. Again, this is different from a fixed shore site which does not move. Mobility of the platform creates a number of complexities both for the platform and the spacecraft.

c. *Electromagnetic Interference*

Electromagnetic interference (EMI) is a large problem for ships. Ships are relatively small and electronic systems are required to be located physically near one another. Interference can occur between systems which operate in or near a common frequency band. It can also occur if one system has a harmonic which falls in another systems operating frequency. Other means of interference can include radars and other nations communications systems. Shore bases can separate systems by locating them on opposite sides of the base in order to reduce the interference. This is not an option on a ship. Naval users must conduct EMI surveys prior to the installation of a new system to ensure there is no interference

between the new system and existing systems. If interference is found between systems, a study must be conducted to determine the best means of reducing or eliminating it.

5. Network Descriptors

Before discussing circuit requirements for the battle group, it is important to understand certain terms and how they relate to networks. This section identifies network descriptors used to characterize requirements for future MILSATCOM systems.

a. Network Type

There are three basic types of networks used in Naval communications. They are voice, video and data networks. Voice networks transmit voice commands or instructions from one place to another. Data networks are used to create links of digital data connecting different users. Video circuits are relatively new to Naval communications. This is a video link between two or more location that allows information to be transmitted via both audio and video channels.

b. Protection

There is a variety of protection that can be afforded to a communications circuit. It is important to ensure that the protection provided to circuit is commensurate with the data transmitted on that circuit. This is important because greater protection leads to higher cost and possibly less throughput.

For Naval purposes, High protection is defined as nuclear survivable. This type of protection will be provided to national level command and control circuits. Medium

protection offers protection against tactical jammers. This type of protection will be used on vital circuits for deployed battle groups. Low protection is designed to eliminate disturbances caused by nuisance jammers. Finally, None means that the circuit operates with no protection from outside interruptions. [Ref. 17:p. 111]

c. *Data Rates*

Data rate is defined as the speed at which data is transferred. Naval communication systems operate at a variety of data rates. Low data rates are described as those below 9.6 Kbps. Medium data rates are those between 9.6 Kbps and 1.544 Mbps. High data rates are those which are greater than 1.544 Mbps. [Ref. 17:p. 111]

d. *Mobility*

Communications are required continuously between operational Naval units. Ships are mobile in every since of the word, but are larger and more capable than many other mobile platforms which also require SATCOM capabilities. This means that ships have enough space to maintain suits of communications gear. This is not true with all mobile units. It is important to consider unit size and capabilities needed when determining requirements for a SATCOM system. Some of the different types of units to be analyzed are land mobile units such as command vans, man-portable units such as a man pack, ships, submarines and aircraft. Each of these platforms have different communication needs and capabilities which must be recognized and prioritized during the requirements generation process. [Ref. 17:p. 111]

e. Topology

There are many forms of topology which can be implemented in a communications network. The type of topology chosen for a particular network should best support the amount of traffic and the sensitivity of the data transmitted on that circuit. The topology most often utilized by Naval users is a Netted circuit. A netted circuit is defined as an open channel with multiple users on it at the same time. Users access the network as required, but all other users are able to hear their transmission. Hub and Spoke is another popular topology. Here there is a central net control center with other users able to access the network by going through the control center. When drawn out it appears as a hub with spokes radiating from it. There is also the standard point-to-point configuration. This is similar to a telephone call where there is one caller and one receiver. Other forms of networks which are gaining in popularity are broadcast networks and virtual networks similar to the Internet. A broadcast network is a circuit with a central control station that transmits broadcasts to all net participants. Only the central control station is permitted to transmit on the circuit. A virtual network can best be described as similar to the Internet. Users would access the circuit to retrieve required data. [Ref. 17:p. 111]

f. Coverage

A communications network can be designed to provide a variety of coverages. Some links are intended to operate only inside a particular unit similar to a Local Area Network (LAN). Other networks might be used for intra-battle group links to provide connectivity for local units. Other, more far reaching, forms of coverage are also required.

Theater commanders want control over all units operating in their areas of responsibility. This creates a need for regional networks. There is also a need for reach back to the continental United States, and some global communications networks. [Ref. 17:p. 111]

6. Circuit Requirements

There are specific requirements for the type and number of circuits to support a carrier battle group in the future. These requirements are broken down into three categories: voice, video and data. This section describes specifically described fleet circuit requirements.

a. Voice Requirements

There are a total of 300 voice circuit requirements which have already been defined for a CVBG. The following is a breakdown of those requirements.

Of the 300 voice circuits, coverage is divided among shore (trunk lines), shore (discrete lines) and Intra-Battle Group circuits. Shore trunk lines are large bandwidth circuits which are transmitted, via satellites, to the shore. These channels may transmit many individual circuits at one time. A shore discrete line is a channel which transmits only one circuit back to a shore site via a satellite transmission. There are to be 120 shore (trunk lines) and Intra-Battle Group circuits. There will also be 60 shore (discrete lines). [Ref. 17:p. 105]

The topology of the voice circuits is broken down into netted and point-to-point circuits. 80% of the circuits are point-to-point. The other 20% of the circuits are netted. [Ref. 17:p. 105]

The quality of the circuits will be either high or basic quality. Only 40% of the circuits will be high quality while the other 60% will be basic quality.[Ref. 17:p. 105]

The protection afforded to each circuit will differ according to the importance of the information carried. 38% of voice circuits will have no protection. 40% will have low protection. 20% will have medium protection which will leave the final 2% with high protection. [Ref. 17:p. 105]

b. Video Requirements

The Naval Space Command Functional Requirements Document defines future requirements for 20 video circuits to support a CVBG. The following is a breakdown of those circuits.

The 20 video circuits will be required to provide coverage over varying geographical areas. Only one circuit will be required for global communications. Five circuits will be necessary to provide connectivity with the continental United States. There are also five circuits identified as regional requirements. The remaining nine circuits are to be used for intra-battle group communications. [Ref. 17:p. 105]

There are three data rate requirements related to video circuits. Four of the circuits will require data rates of 64 kbps. The majority of the circuits, 12, specify a requirement for 256 kbps. The remaining four circuits are required to operate at 2.048 Mbps. [Ref. 17:p. 105]

Varying topology requirements have been specified for battle group video circuits. Six of the circuits will be used for broadcast purposes. Four circuits will be required for point-to-point communication. The remaining ten circuits will provide netted access for users. One example of this type of access could be the Battle Group Commander's nightly

'fire-side chat' with his unit commanders. [Ref. 17:p.105]

Differing levels of protection have been specified for battle group video circuits. One half, 10, of the circuits will require no protection. One circuit has been specified as requiring low protection. The remaining nine circuits will be provided with medium protection. [Ref. 17:p. 105]

c. Data Requirements

Naval planners have determined that future CVBG operations will need 285 data link circuits to meet all information requirements. These links will provide majority of the CVBGs information requirements as opposed to voice or data circuits.

Future battle group data communications will be similar to current links in that they will be call upon for connectivity both on a global and a unit level. 14 links will be specified to provide global coverage for commanders. 71 circuits will be employed for communication with the continental United States. 157 circuits are identified as regional communication links. The remaining 43 circuits are for intra-battle group communications. [Ref. 17:p. 105]

Differing data rate requirements have been specified for battle group data circuits. 171 of these data links will provide services at rates of 9.6 kbps or less. Only 37 are to operate at 64 kbps. 71 circuits will provide service at either 256 kbps or 512 kbps. The remaining six circuits will employ data rates of 2.048 Mbps. [Ref. 17:p. 105]

As with the other types of circuits, data circuits will be afforded protection based upon the information they carry. 28 circuits will require no protection. 29 circuits have

been identified as requiring low protection. The majority, or 214 circuits, will be provided with medium protection. The remaining 14 links will operate with high protection. [Ref. 17:p. 105]

The topology of data circuits will vary depending on the purpose of the circuit. 28 data links will be used as broadcast channels to support the battle group. 143 circuits will be incorporated as hub and spoke data links. 86 data links have been specified as point-to-point circuits. The remaining 28 circuits will operate in a netted fashion. [Ref. 17:p. 105]

7. SATCOM Vulnerabilities

There are a number of vulnerabilities associated with satellite communications. Satellite footprints are generally very large. Information is transmitted from the spacecraft to all points within the beam footprint. Any forces within that area are capable of receiving the transmission. The relatively stable position of a GEO spacecraft creates a target for an adversary and a potential vulnerability for the system. LEO satellites are predictable and, therefore, are also vulnerable. Ground stations provide another point of weakness in the system. This section of the thesis will explore the vulnerabilities associated with different links throughout the communication chain.

a. Communications Channel Jamming (Non-destructive)

Jamming is defined as "transmitting a large modulated carrier to a receive terminal at approximately the same frequency, overwhelming the desired signal and thus disabling the link." [Ref. 7:p. 548] Any receive terminal may be subjected to some form of jamming, either intentionally or incidentally. Jamming is a form of Electronic Warfare (EW)

and is a relatively inexpensive means to impair a communications system. An adversary may target the space segment, terminals or even the terrestrial network to disrupt military command and control functions. Protection against EW is vital to the effectiveness of a communications network. It is important to identify methods to protect the system against the effects of jamming.

(1) SPACE SEGMENT. The space segment of a geosynchronous communications satellite system is the most vulnerable segment of the network. This is because the location of the satellite is commonly available through public information sources. Ephemeris data for all Earth orbiting satellites can be found on the Internet. This data provides a detailed description of the orbital parameters for a particular spacecraft. Such information would provide a potential adversary all data necessary to target any satellite.

A well designed MILSATCOM architecture must be capable of addressing EW threats. The communications system must include some form of anti-jam (AJ) or electronic counter countermeasures (ECCM) capability for each of its various links. Instituting such capabilities, however, reduces the total capacity of the system. These protective measures require more power and bandwidth to increase communications security. This, therefore, reduces the amount of bandwidth available for data transmission. [Ref. 20:p. 109]

The degree to which a communication system may be jammed is dependent on the operational characteristics of that system. The following are a few of the critical factors which must be considered throughout the system design process: Transmitter power, type of modulation employed, bandwidth utilized, frequency agility, receiver design,

antenna gain and directivity, antenna steerability, and the ability to adapt the transmission format and data rate in response to a jamming event. Successful communication systems should carefully incorporate all of the above characteristics into the development of the system. This will improve the operational effectiveness of the system in a jamming environment. [Ref. 21:p. 342]

Current systems have developed some AJ or ECCM techniques to ensure more secure communication for network users. The first of these is spread spectrum transmissions. In spread spectrum transmission, the carrier is spread over a wide bandwidth through the use of a spreading code. "The noise-like character of the transmitted signal is produced by having an information-bearing binary sequence modulate a bandwidth spreading sequence that acts as a carrier." [Ref. 22:p. 550] A receiver must have the code used to spread the signal in order to recover it. This increases the security of the system because the carrier wave is 'hidden' in the transmission noise floor and the receiver has to have the correct code to reproduce the transmitted information. The signal may still be jammed, but it is more difficult for an adversary to identify the target transmission frequency.

Other techniques which may be employed to reduce the effectiveness of jamming on a system are: "increased effective satellite power for the ground terminals, satellite receive antenna discrimination, processing transponders, and increased effective power in the satellite." [Ref. 21:p. 342] The use of these techniques either by themselves or in concert will increase the resistance of the system to jamming.

(2) TERMINALS. Terminals are susceptible to jamming in the same manner as the spacecraft is. Measures must be taken to protect user terminals from jamming

in addition to the protection provided to the satellite. An adversary only has to interfere with one segment of a communications network to effectively jam the entire system. It would, therefore, be a waste of tax dollars to protect the space segment from jamming and neglect other segments.

One of the most effective means of protecting the terminal is spread spectrum transmission. Network receivers should be the only terminals with the spreading codes. An adversary would have a difficulty detecting the transmission. Other methods of protection could include more directional antennas and increased active ECCM methods.

(3) NETWORK. Networks require protection from jamming and intrusion as do the satellites and terminals. Some effective means of protecting a network are DAMA polling and user protocols. Polling refers to a central control station querying participating units at defined intervals and requiring a 'pass word' for access to the network. Once the control station verifies their identification, reporting stations are allowed to make reports and receive updates. Protocols are defined as "a software design that specifies the details of how computers interact, including the format of messages they exchange and how errors are handled." [Ref. 23:p. 467] Computers wishing to participate in the network require a copy of the protocols to effectively transmit and receive data.

b. Electronic Attack (Destruction or Impairment)

Unlike jamming, an electronic attack is intended to either destroy or impair the target system or sensor. An adversary may eliminate a communications link by carrying out an electronic attack on the space segment of a system. Terminals and fiber lines may be

repaired relatively easily. Satellites are generally not repairable once they have been damaged. With this in mind, it is important to consider methods of countering electronic attack when designing a space based communications network.

(1) SPACE SEGMENT. Communications satellites contain very sensitive receivers to detect ground based transmissions. It is possible to damage or destroy some of these sensors by transmitting an extremely strong signal on or near the tuned frequency of some of these components. The low-noise amplifier, high-power amplifier and mixers are vulnerable to this form of electronic attack. These components require protection from electronic attack. One means of providing this protection is installing filters to eliminate signals which exceed a certain strength threshold. This would reduce the power allowed into the components and thus, prevent damage to them.

(2) TT&C FUNCTIONS. Electronic attack may also be carried out against the control functions of a satellite. Each satellite requires station keeping and command signals from ground stations. If an adversary were able to duplicate these signals, they could send damaging commands to the satellite. They could change the orbit, switch off components or possibly de-orbit the spacecraft. If they are unable to duplicate the transmission to the satellite, they could simply jam friendly commands to the spacecraft. This would prohibit friendly users from accessing the vehicle to update missions and station keeping data. In either case, friendly usage of the satellite has been reduced or excluded.

Highly directional antennas, spread spectrum transmissions and data encryption provide some solutions to these issues. The above techniques, when used in unison, make unfriendly interference with TT&C functions very difficult.

c. *Physical Destruction*

Many nations do not possess the technical capability to jam or electronically interfere with U.S. communication systems. Physical destruction of a communication node provides these nations, or other organizations, with a means of disrupting military communications through the use of classical military hardware or other non-conventional methods. It is vital to the effectiveness of the system that these low-technology threats be identified and addressed during the system design process. Early identification of system threats allows greater flexibility in designing a secure and physically protected system.

(1) NETWORK CONTROL CENTER (NCC). The Network Control Center is the command center for a communication system. It exercises control over the operation of system components. Generally the NCC is a facility or complex that houses the majority of the computing capacity for a communications system. This is an easily identifiable target for those wishing to disrupt communications. It can be physically destroyed or damaged to hamper its operation. There are also other means of attacking the NCC such as cutting its power supply, injuring key personnel, or interrupting other utilities.

It is important to identify potential physical threats to a specific network command facility. By identifying these threats, steps can be taken to isolate and protect the system and personnel. Constructing the complex in a secluded location and providing a modern security systems is a good start. Command centers located in populous areas are much easier targets because they are simpler to reconnoiter and plan an attack. In general, relatively simple methods can be used to protect the NCC from physical attack. The key is to develop a comprehensive list of the physical threats which a facility might face.

(2) SPACE SEGMENT. The space segment is vulnerable to physical destruction. Satellites maintain nearly constant orbits and have no onboard defensive systems. A technologically advanced adversary could carry out a successful anti-satellite (ASAT) attack on some U.S. space based assets. It would be difficult, if not impossible, to destroy the entire U.S. space arsenal because of the numbers of spacecraft currently in orbit. This does not mean, however, that the loss of one or two satellites would not harm military operations. There is no system available to replace a MILSTAR spacecraft if one were destroyed. Currently the only means of protecting from an ASAT attack is to identify a potential attacker and destroy their vehicle prior to launch. Once they have launched, there is no system to intercept the threat spacecraft. The only means of avoidance is to alter the orbit of the target satellite significantly. This requires large amounts of fuel and reduces the life of the satellite.

(3) NUCLEAR. Both the space and ground segments are vulnerable to nuclear attack. Blast and radiation can adversely effect the performance of both segments. MILSTAR and some other systems were designed to survive nuclear attacks. They were hardened to provide protection against the increased radiation caused by an exo-atmospheric nuclear detonation. They cannot survive blast effects though. The only means to prevent nuclear attack on U.S. ground or spaced based assets is through diplomacy and compliance with the Nuclear Non-Proliferation Agreement.

d. Signals Intelligence (SIGINT)

U.S. space based communications assets are subject to SIGINT collection. An intelligence collector inside the footprint of a satellite downlink has the capability of copying that signal. Migration to higher frequency communication has the potential to limit the collection of U.S. signals. Higher frequency systems have smaller footprints, thus making it harder for a collector to enter the transmission area without alerting friendly forces. Spread spectrum transmissions also make it more difficult for intelligence organizations to collect data on satellite transmission. One important consideration is to provide protection commensurate with the data being passed on a network. This, combined with other communications security methods, smaller beam widths and spread spectrum will limit friendly vulnerability to SIGINT.

IV. SYSTEM LOADING METHODOLOGY

A. MAJOR SCENARIO ASSUMPTIONS

In developing a scenario for the loading analysis, certain assumptions were made with regard to specific aspects of military operations. The purpose of this section is to explain the assumptions which were made during this analysis. This will provide the reader with a better understanding of the study results.

1. Assumptions for Emerging Naval Requirements

Naval Space Command developed certain assumptions about future SATCOM capabilities, which were derived from the Naval Satellite Communications Functional Requirements Document (FRD)[Ref. 17]. These assumptions were then used as entry points into the ERDB for the analysis. The ERDB describes communications requirements anticipated in the near future. These future requirements are derived from expected technological advancements. The major assumptions for this study are listed below:

- The data rate for basic voice quality is 2.4 kbps; high quality voice is 4.8 kbps.
- Netted voice is high quality.
- The following data rates generally apply for data and video communications: Low data rate (LDR) < 9.6 kbps, medium data rate 1 (MDR1) = 64 kbps, medium data rate 2 (MDR2) = 256 kbps or 512 kbps, and high data rate (HDR) = 2.048 Mbps.
- The Naval Computer and Telecommunications Master Station (NCTAMS) functions as the interface between Joint and/or Navy shore commanders and Naval forces afloat for all MDR and HDR requirements. LDR voice and data communications between afloat forces and commanders ashore can be direct (i.e., bypass the NCTAMS).

- The NCTAMS functions as the hub for hub-spoke circuits and extends these circuits to regional, continental United States, and global users.

- Broadcast service consists of discrete links (e.g., Fleet Broadcast) and information that can be consolidated on the global broadcast service channels such as imagery, weather data, and Armed Forces Radio and Television.

- The Fleet Broadcast is highly protected; all other broadcast service requires low or no protection.

- When Naval forces are outside the GBS high throughput spot beam, those broadcast circuits that are normally consolidated onto a single GBS channel become discrete broadcasts. [Ref. 4:p. 9]

2. Assumptions for Emerging Marine Corps Requirements

The Marine Corps makes up one half of the Naval team. The Marine Corps relies on Navy amphibious ships to execute their mission. ARG units play an important role in modern naval operations and, as can be seen in Forward...From the Sea, they will continue to do so for years to come. Amphibious units provide tremendous flexibility to national planners by their inherent ability to strike at almost any coastal location. The Marine Corps brings their own set of emerging requirements to the loading analysis. As with the emerging Naval requirements, Marine Corps requirements from the FRD were translated into suitable format for the loading analysis. The major requirements used for the analysis are listed below.

- Marine Corps ERDB requirements apply only when Commander Marine Forces (COMARFOR), Marine Expeditionary Forces (MEF) and Marine Expeditionary Units (MEU) are deployed as ground forces in the theater of operations. The Navy satisfies information requirements for COMARFOR, MEF and MEU while aboard ships.

- The data rate for basic voice quality is 2.4 kbps; for high quality voice it is 4.8 kbps, with the exception of the Defense Switched Network (DSN) and the Defense Red Switched Network (DRSN) which are 64 kbps.

- Netted voice, DSN, DRSN, and voice channels that accompany video service are high quality. Other voice services are a mixture of high quality and basic quality.

- The following data rates generally apply for data and video communications: Low data rate < 9.6 kbps, MDR1 = 64 kbps, MDR2 = 256 kbps or 512 kbps, and HDR = 2.048 Mbps.

- Broadcast service consists of discrete links (e.g., Tactical Information Broadcast System) and information that can be consolidated on GBS channels such as imagery and weather data. The GBS spot beams will be available to the COMARFOR, MEF and MEU deployed in a theater of operations.

- Broadcast services for COMARFOR, MEF and MEU require low or no protection.

- Hub-spoke connectivity within the Marine Corps' ERDB requirements set applies to ground mobile forces (GMF) circuits.

- COMARFOR and MEF video teleconference (VTC) requirements are included in the Defense Information Systems Network (DISN) and telemedicine requirements are included in the MEF combat service support element N-Level Internet Protocol Router Network (NIPRNET). [Ref. 4:p. 10]

3. Architecture Payload Design Assumptions

With the exception of the UHF F/O spacecraft, all satellites included in the analysis are conceptual models. As such, certain assumptions were made concerning the satellite payload design and employment. The basis for the assumed designs was the proposed architecture developed by the Office of the DoD Space Architect. This section will outline the assumptions made for each class of satellite.

a. UHF F/O Payload

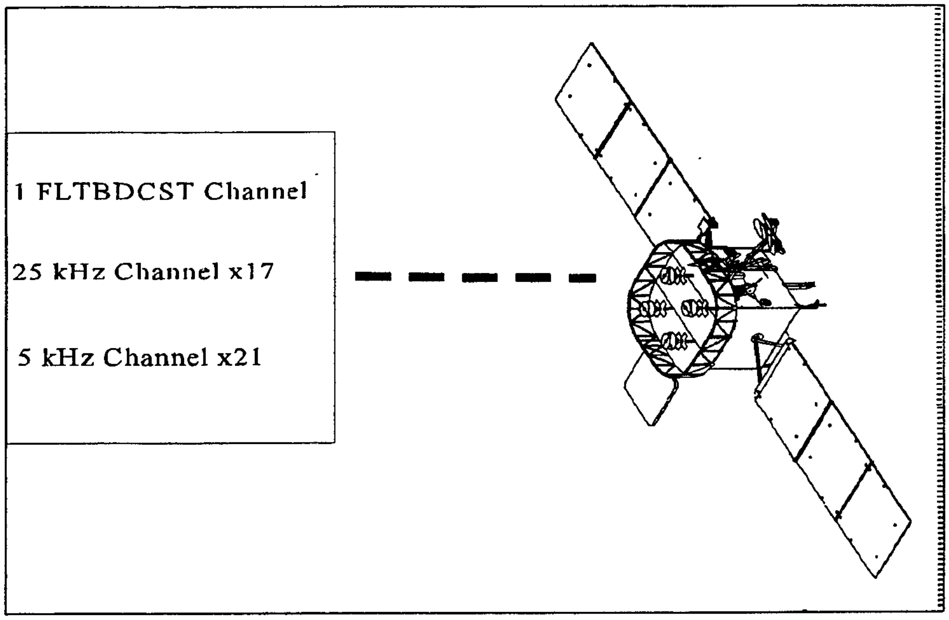


Figure 4.1. UHF Payload Configuration. [Ref. 4:p. 17]

The UHF F/O constellation for the 2008 architecture will have four pairs of satellites in geosynchronous orbits. Each of the pairs will be separated by 90°. These satellites will provide global coverage up to seventy degrees North and South latitude. Figure 4.1 provides an illustration of the payload configuration on a UHF F/O spacecraft. The UHF communication subsystems will consist of several 25 kHz and 5 kHz channels. Signals are received and amplified at the satellite, then transmitted back to terrestrial users. The spacecraft will also have the capability of receiving certain SHF uplinks. "The SHF communications subsystem receives broadband-jamming-protected uplink signals of the Fleet Broadcast channel; up to three Fleet Broadcast channels can be multiplexed for simultaneous reception." [Ref. 24:p. 296]

The majority of the UHF F/O spacecraft have an EHF LDR payload. "Only the UHF payload is considered in this loading study because the Advanced EHF (A/EHF) satellites, the follow-on to the MILSTAR satellites, are capable of handling all EHF requirements." [Ref. 4:p. 17] It is important to realize, however, that this study only loads a percentage of the actual military requirements. Army and Air Force requirements are neglected while Naval requirements have been loaded. This is in keeping with the purpose of the study.

The Navy currently employs UHF communications primarily to support mobile users. Voice services can be provided at data rates between 2.4 and 9.6 kbps. This meets the voice requirements specified in the ERDB, but does little to satisfy other high data rate requirements. UHF terminals are currently in use throughout the fleet. They are light weight and inexpensive which makes them ideal for mobile units.

b. SHF/Ka Payload Assumptions

The SHF constellation consists of five spacecraft in geosynchronous orbit. The Ka designation refers to the GBS payload which is to be built into the satellite. Figure 4.2 provides an illustration of the assumed configuration for the spacecraft payload. The stationing of the satellites will be such that each ocean area, with the exception of the Pacific, will have one satellite providing coverage. The Pacific area will have two spacecraft stationed above it.

"The SHF/Ka payload design includes four 2.2° SHF antennae, frequency reuse, and a radio frequency (RF) switch allowing uplinks from one beam to be routed on the

downlink to another beam." [Ref. 4:p. 18] Specifically the SHF system will provide medium to high data rate transmissions to its users. Shipboard capabilities are limited by the size of the receive antenna. Larger platforms such as carriers and command ships will have larger terminals which will support higher bandwidth transmissions.

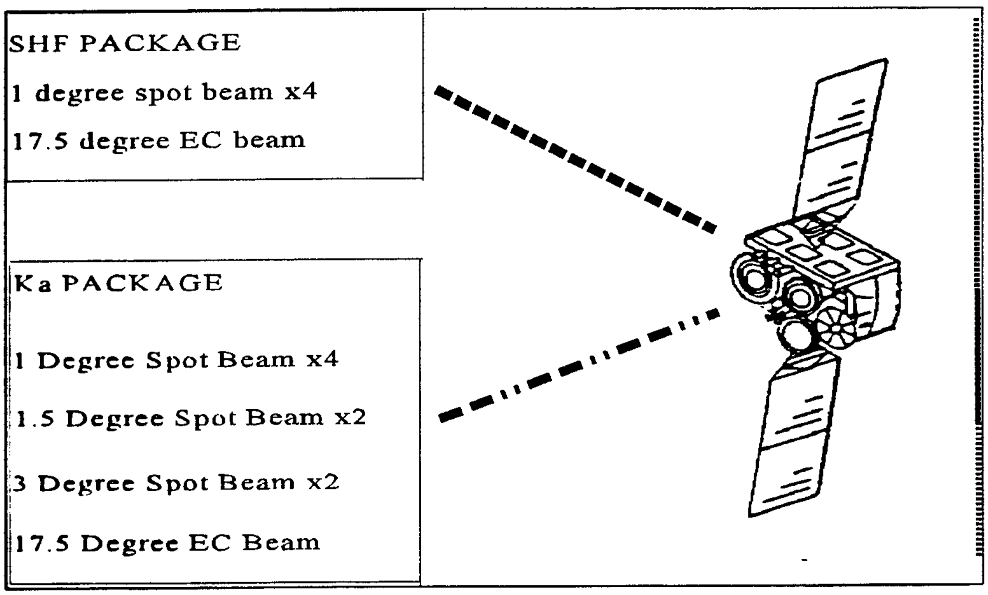


Figure 4.2. Assumed SHF/Ka Payload Configuration. [Ref. 4:p. 18]

c. *EHF Payload Assumptions*

The EHF constellation will consist of four MILSTAR and nine UHF F/O spacecraft in geosynchronous orbit. As mentioned earlier, the UHF F/O spacecraft will not be considered during the EHF loading. All of the MILSTAR spacecraft will be equipped with both the Advanced EHF LDR and MDR payloads.

Figure 4.3 provides an illustration of the anticipated MILSTAR EHF payload configuration. The LDR payload has one Earth coverage receive horn, one Earth coverage

transmit horn, two narrow spot beam transmit/receive antennas, one wide spot beam transmit/receive antenna, five electronically steered agile receive antennas, and one agile transmit antenna. The MDR payload hosts a suite of eight steerable spot beam antennas. Two of these are narrow spot beams (NSB) and the remaining six are distributed user coverage antennas (DUCA). The NSBs have an onboard nulling capability which significantly increases the jam resistance of the MDR system. [Ref. 4:p. 19]

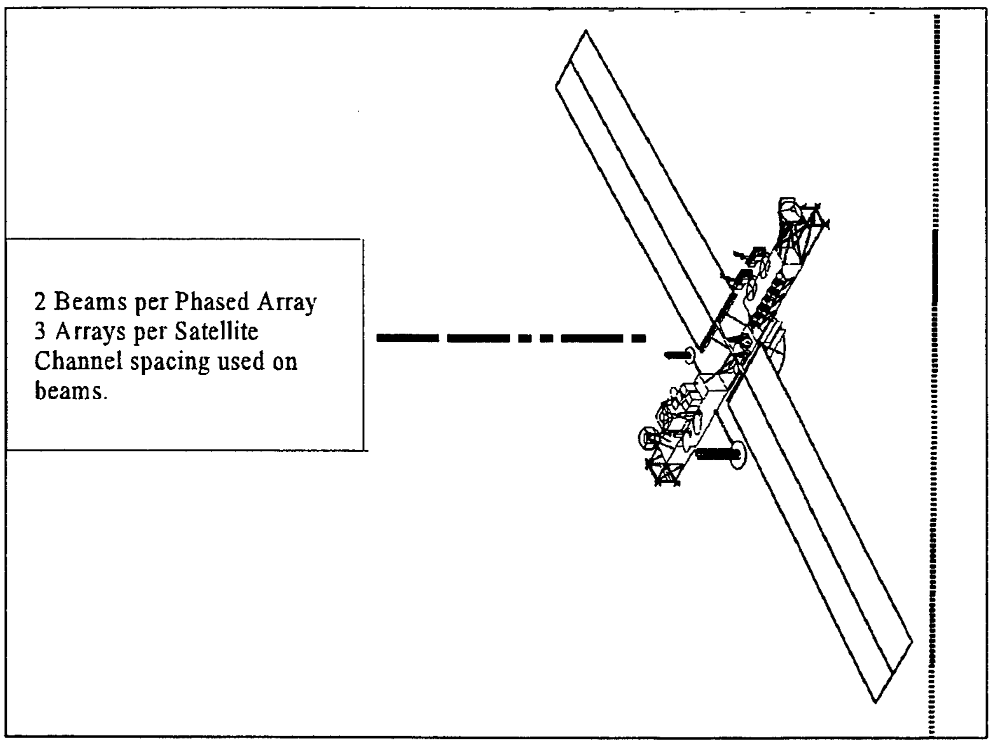


Figure 4.3. Assumed MILSTAR EHF Payload Configuration. [Ref. 4:p. 20]

B. SCENARIO FORCE STRUCTURE

The force structure for this analysis has briefly been discussed in previous chapters. A limited sample of the force structure used for this loading is located at the end of the

chapter in Table 4.2. It is important to note that forces deployed in LRCs might not consist of both a CVBG and an ARG. Forces are deployed where and when they are needed. One example of this is LRC4 in Table 4.2. This LRC is supported only by ARG units. This situation can be considered analogous to recent operations in Somalia where only amphibious forces were used to support forces ashore.

It is also important to recap the constituents of different battle groups. We will begin with the CVBG. The CVBG is centered around the carrier. There are also numerous support ships to aid and screen the aircraft carrier. These ships include cruisers, destroyers, frigates, submarines and other support vessels. Associated air wings and staff units are included with the ships for the loading. All SATCOM capabilities which are normally associated with a CVBG at sea are included in the scenario.

The ARG is the second formation of ships and forces which is discussed. An ARG is centered around a large deck amphibious assault ship, usually an LHA or LHD. In addition to the assault ship, there are two LSDs and an LPD in the group. Once again, traffic here is meant to represent the normal amount of SATCOM traffic associated with an ARG which is operating under normal deployment conditions.

There are ten CVBGs and ten ARGs loaded into the scenario. Some of the groups are in port in the United States. Other units are conducting workups in U.S. coastal waters. Still other groups are in transit to and from deployment areas such as the Mediterranean Sea and the Persian Gulf. The remainder or the forces are deployed and operating in normal areas. The scenario analyzes the traffic generated by each of the units in their various locations while conducting daily operations. This enables the correlation of SATCOM traffic

levels to unit locations and the operations performed.

The force structure for the loading analysis is built up unit by unit.[Ref. 4:p. 13] The ERDB identifies the numbers and types of circuits required for each platform. As the communication suit for each unit is created, they are then summed into the remainder of the battle group they are associated with. This allows an in-depth look at the traffic loading which will then identify the circuits or systems carrying the majority of the communications load. The loading also considers the relative distance between platforms in the analysis. "By using the relative distance approach, the CVBG object can be associated with any location and the units associated with the object take on the same location without having to make individual assignments to each of them." [Ref. 4:p. 13]

C. STUDY METHODOLOGY

This purpose of this section is to explain the methodology that was used while conducting the system loading. It will cover such issues as transponded versus processed signals and DAMA usage. In addition to this, it will also investigate the configuration of each of the different classes of satellites for the purpose of the loading analysis.

1. Transponded Versus Processed Satellite Transmission

The analysis was required to distinguish between transponded and processed signals. Transponders are simply active microwave repeaters which are carried on most of the communications satellites. These instruments are well understood and proven technologically which means that a transponding satellite can generally be expected to cost less than a processing satellite. Processing satellites have computers onboard which modify or process

the up-linked signal. Processing satellites are able to realize a signal gain through their processing capabilities and therefore enhance signal quality. They also provide other advantages in terms of digital transmissions and anti-jam capabilities. The negative aspects of onboard signal processing is that the added computer increases the weight and the complexity of the satellite. This infers that the processing satellite will cost considerably more than its transponding cousin.

For the purposes of this analysis, certain assumptions were made with respect to transponding and processing satellites.

The study considers the UHF and SHF/Ka payloads to be transponding systems and the A/EHF payload to be a processing system. With transponding systems the loading of a link is dependent upon the bandwidth demand on the transponder. To determine the exact loading on a transponding satellite requires that all requirements for platforms in that satellites footprint be evaluated. The number and bandwidth of all channels required are calculated and then subtracted from the available capacity of that satellite. This is not true of processing systems. Processing satellites have the same resource requirements for a link regardless of the loading of other traffic on the payload; therefore, this study is able to load each conflict individually and sum the results. [Ref. 4:p. 27]

2. UHF With DAMA Loading Methodology

"The UHF loading is the most simplistic of the study in that it assumes the link can be made given the terminal is in the footprint of the satellite and capacity is available." [Ref. 4:p. 28] When a conflict between terminals for capacity arose, the loading fell back on a

priority based system. The highest priority in the loading was given to CVBG units. The next highest priority for access went to ARG units. Third priority was designated for Marine Corps terminals, and this was followed by all remaining requirements. [Ref. 4:p. 28]

DAMA is Demand Assigned Multiple Access. It was originally created as a means of reducing congestion on FLTSAT assets. DAMA is a system which provides a means of performing Time Division Multiplexing (TDM) on various channels in multiple formats. The major advantage in DAMA is that it allows multiple transmissions on the same channel instead of one transmission per channel. This increases the efficiency of the system tremendously. [Ref. 24:p. 280]

The technical specifications for the UHF loadings are listed below:

Each satellite uses four frequency plans, two per footprint. In each footprint there are four broadcast channels, thirty-four 25 kHz channels and forty-two 5 kHz channels. Of these channels, 75% use DAMA (i.e., twenty-six of the 25 kHz channels per footprint and thirty-two of the 5 kHz channels per footprint). A 25 kHz automatic control DAMA channel with 15 frame formats can support four 2.4 kHz voice/data networks or three 2.4 kHz voice/data networks and one 4.8 kHz voice/dama network. Service greater than 4.8 kHz requires a dedicated channel. A 5 kHz automatic control DAMA channel supports Navy requirements up to 2.4 kHz voice/data networks.[Ref. 4:p. 28]

The Navy DAMA network varies depending upon the situation and requirements of the forces being supported. Baseband equipment input/output can be 75 bps, 300 bps, 600 bps, 1.2 kbps, 2.4 kbps, 4.8 kbps and 16 kbps. The Navy DAMA network multiplexes several baseband subsystems on one 25 kHz transponder channel using a time division multiple

access (TDMA) system. DAMA network control stations are normally the NCTAMS, but any platform with full duplex capability can be designated a DAMA controller channel. [Ref. 4:p. 28]

3. SHF/Ka (GBS) Loading Methodology

Several assumptions were made for the SHF/Ka (GBS) loading. "The combined SHF/Ka payload design provides for a radio frequency (RF) switch that allows uplinks from one beam to be routed on the downlink to another beam." [Ref. 4:p. 29] The SHF/Ka loading considers both the duplex communications of the SHF platform and the broadcast capabilities of the Ka (GBS) transponder. Only spot beams were considered for the loading analysis. The lack of a transponder switch to an earth coverage (EC) antenna negated the wide area beam. This means that all SHF communications were conducted by employing the system 2.2° spot beam. No EC beams were used in the loading. Quadrature Phase-Shift Keying (QPSK) was the modulation chosen for the analysis.[Ref. 4:p. 29]

The technical specifications of the SHF/Ka loadings are discussed below.

The initial step in loading the SHF/Ka is to perform a baseline calculation to determine the percentage of satellite power and bandwidth required for 1000 bps. This percentage can be scaled to any data rate. The scalability of the results is important. It allows the evaluation of higher bandwidth signals by simply applying a simple scaling factor. Table 4.1 shows the results of the simplified calculation of transponder power and bandwidth use. The results of the table constitute the scaling factors which are applicable to all transmission. These results show, in the bandwidth percentage cell, that any 1 kbps service in the scenario requires

0.0018% of the transponder bandwidth. Note that in Table 4.1, two instances appear to be power limited rather than bandwidth limited. Both the EC to EC and Spot to EC for the 7 foot receiver are power limited. This is evident because more power is used for each transmission than bandwidth. The study assumes that in this scenario all terminals with a 7 foot antenna in the carrier battle group are covered by spot beams and not EC beams. Because there is thus no requirement for a terminal to receive in the EC beam, the power limitation is not an issue.[Ref. 4:p. 29]

Receiver		EC to EC	EC to Spot	Spot to EC	Spot to Spot
7 ft	Power %	4.5E-05	1E-05	4.1E-05	5E-06
	Bandwidth %	1.8E-05	1.8E-05	1.8E-05	1.8E-05
20 ft	Power %	1.4E-05	9E-06	1E-05	5E-06
	Bandwidth %	1.8E-05	1.8E-05	1.8E-05	1.8E-05

Table 4.1. Transponder Power and Bandwidth Use. After [Ref. 4:p. 29]

4. EHF Loading Methodology

There are four EHF satellites in the proposed architecture. Each of these satellites is separated by 90° to ensure world wide coverage. "Beams are positioned to cover Naval forces participating in the four LRCs, the MRC and background operations." [Ref. 4:p. 30] Efforts were made throughout the loading to ensure minimum beam usage in all situations. One example in the MRC is the use of a 5° spot beam to cover all Naval units involved rather than multiple smaller spot beams to cover each battle group. The assumption is made that shore terminals, which are outside the spot beam, are covered by the Earth Coverage beam,

and a 1° spot beam is used to cover a battle group underway in open ocean steaming. [Ref. 4:p. 30]

Technical aspects of the EHF loading are listed below:

The number of uplink channels and downlink hops used per payload are determined based on link budget calculations. The MILSTAR Interface Control Drawing, SI-1135 and SI-2035, contain tables that map required carrier-to-noise ratio (C/N) to modulation mode. The least robust modulation mode a terminal type can support in each satellite beam is determined by calculating the C/N for the uplink and downlink of each terminal type in each satellite beam type. The number of hops for each service is calculated given the modulation mode for each service participant, the number of satellite beams used in the service, the required data rate, and connectivity.[Ref. 4:p. 31]

The total number of uplink and downlink hops per satellite is determined by summing the hops for each service on the satellite. Uplink hops are totaled and divided by the number of hops in an uplink channel to determine the number of uplink channels. In addition, the uplink hop calculation is tracked on a service participant basis to determine the total number of uplink hops used by each terminal. The calculation makes the following assumptions:

- C/N associated with the 1+8*DPSK mode is an assumed value based on the other DPSK modes corresponding C/N values.
- Performance of QPSK modes is equal to twice the performance of DPSK modes (e.g., C/ required for 16+320 QPSK = 2 x C/N required for 16+320 DPSK).
- Use the unstressed data rate with and without jamming to facilitate analysis and comparison.
- A contiguous set of uplink accesses are always available, assuming the number of

accesses could be provided.[Ref. 4:p. 31]

MRC				LRC1	LRC2	LRC3	LRC4
CVBG1	CVBG2	CVBG3	CVBG4	CVBG5	CVBG6	CVBG7	CVBG(N/A)
CV1	CV2	CV3	CV4	CV5	CV6	CV7	
CG1	CG3	CG5	CG7	CG9	CG11	CG13	
CG2	CG4	CG6	CG8	CG10	CG12	CG14	
DD1	DD3	DD4	DD6	DD7	DD9	DD10	
DD1	DDG2	DD5	DDG5	DD8	DDG8	DD11	
DDG1	DDG3	DDG4	DDG6	DDG7	DDG9	DDG10	
FFG1	FFG4	FFG7	FFG10	FFG13	FFG16	FFG19	
FFG2	FFG5	FFG8	FFG11	FFG14	FFG17	FFG20	
FFG3	FFG6	FFG9	FFG12	FFG15	FFG18	FFG21	
SSN1	SSN4	SSN7	SSN10	SSN13	SSN16	SSN19	
SSN2	SSN5	SSN8	SSN11	SSN14	SSN17	SSN20	
SSN3	SSN6	SSN9	SSN12	SSN15	SSN18	SSN21	
AOE1	AOR1	AOE2	AOR2	AOE3	AOR3	AOE4	
ATS1	AD/AS1	ARS1	ASR1	ASR2	ARS2	ATS3	
UAV1	UAV3	UAV5	UAV7	UAV9	UAV11	UAV13	
UAV2	UAV4	UAV6	UAV8	UAV10	UAV12	UAV14	
CVAIR1	CVAIR2	CVAIR3	CVAIR4	CVAIR5	CVAIR6	CVAIR7	
ARG 1	ARG2	ARG3	ARG4			ARG5	ARG4
LHA1	LHD1	LHA2	LHD2			LHD3	LHA3
LPD1	LPD2	LPD3	LPD4			LPD5	LPD4
LSD1	LSD2	LSD3	LSD4			LSD5	LSD4
FFG31	FFG32	FFG33	FFG34			FFG36	FFG35
DDG16	DD17	DDG18	DD19			DD21	DD20
UAV21	UAV23	UAV25	UAV27			UAV31	UAV29
UAV22	UAV24	UAV26	UAV28			UAV32	UAV30
AAIR1	AAIR2	AAIR3	AAIR4			AAIR5	AAIR4
LCAC1	LCAC10	LCAC19	LCAC28			LCAC46	LCAC37
LCAC2	LCAC11	LCAC20	LCAC29			LCAC47	LCAC38
LCAC3	LCAC12	LCAC21	LCAC30			LCAC48	LCAC39
LCAC4	LCAC13	LCAC22	LCAC31			LCAC49	LCAC40
LCAC5	LCAC14	LCAC23	LCAC32			LCAC50	LCAC41
LCAC6	LCAC15	LCAC24	LCAC33			LCAC51	LCAC42
LCAC7	LCAC16	LCAC25	LCAC34			LCAC52	LCAC43
LCAC8	LCAC17	LCAC26	LCAC35			LCAC53	LCAC44
LCAC9	LCAC18	LCAC27	LCAC36			LCAC54	LCAC45
AAV1	AAV7	AAV13	AAV19			AAV31	AAV25
AAV2	AAV8	AAV14	AAV20			AAV32	AAV26
AAV3	AAV9	AAV15	AAV21			AAV33	AAV27
AAV4	AAV10	AAV16	AAV22			AAV34	AAV28
AAV5	AAV11	AAV17	AAV23			AAV35	AAV29
AAV6	AAV12	AAV18	AAV24			AAV36	AAV30
MCM1	MCM2	MCM3	MCM4				
MHC1	MHC2	MHC3	MHC4				

Table 4.2. A Sample of Loading Force Structure. After [Ref. 4:p. 12]

V. MILSATCOM LOADING ANALYSIS AND FINDINGS

A. LOADING ANALYSIS

This chapter presents the results of the Booz-Allen and Hamilton loading analysis. [Ref. 4] It begins with a description of analysis tools used to conduct the study. Next, it discusses the scenario build up and findings associated with each stage. Force structures for each stage of the build up will also be explained. This provides insight to areas of high force concentration for each of the scenario stages. At the end of each stage, loading requirements for each of the SATCOM regimes will be provided. Loading of each of the different types of satellites makes it easier to identify shortfall areas of MILSATCOM capabilities.

1. Loading Tools

Loading for this analysis was conducted using a variety of software loading tools. Microsoft Excel proved to be the primary software package used throughout the study. Excel proved to be both efficient and flexible as a loading tool. It is compatible with the ERDB which is also in Excel format. The Personal Computer Satellite Orbit Analysis Program (PC SOAP) was used to model satellite orbits and determine which satellites would provide service to a particular geographical region. A Beta version of a loading tool known as WINSAT was tested for this study. This tool, while very promising, proved too immature for the depth of this analysis.[Ref. 4:p. 27]

B. LOADING SCENARIO BUILD UP

The loading was performed in three distinct phases. This section of the thesis will examine each stage of the loading as a distinct segment. Attention will be focused on force distribution, military activity and satellite resources required to support operations.

1. Stage 1 Loading Results

"Stage 1 of the loading analysis examines the resources required for supporting background operations plus two LRCs, the Persian Gulf with a JTF commander embarked and Bosnia." [Ref. 4:p. 35] Figure 5.1 provides the loadings required to support the above-mentioned operations. The loading displayed in this figure represent the total capacity required for the entire MILSATCOM system and not any particular satellite. The following sections will identify the capacity required from each satellite in each of the specific classes.

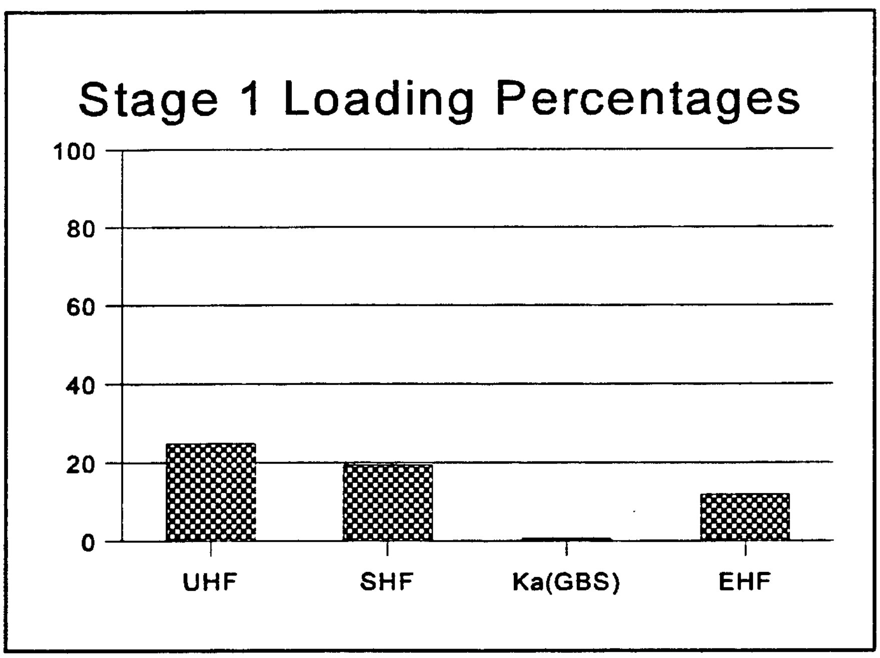


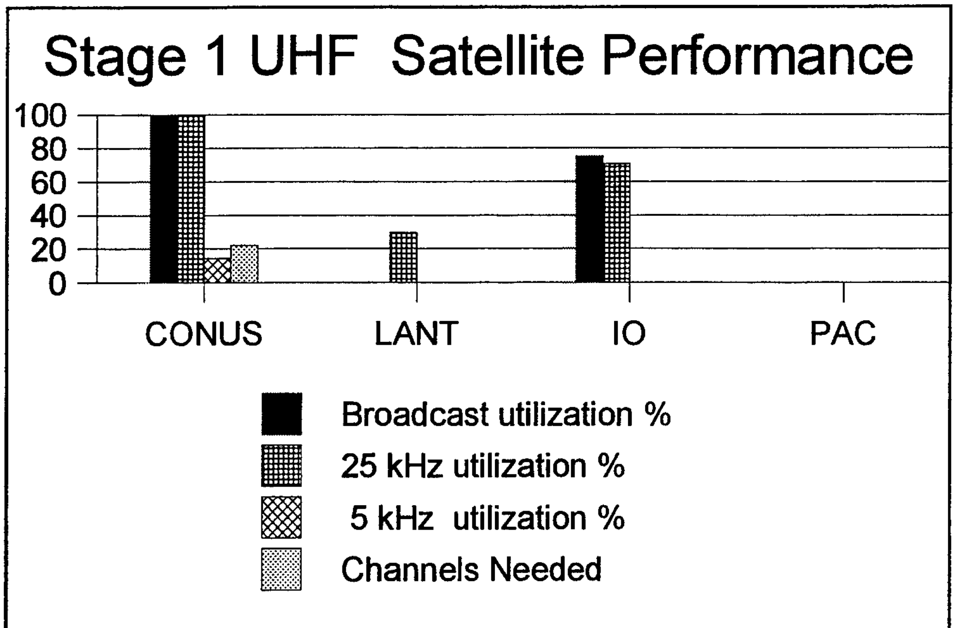
Figure 5.1. Stage 1 Naval Loading Percentages. After [Ref. 4:p. 36]

a. *UHF Loading Performance*

Figure 5.2 provides a summary of the UHF performance on a satellite by satellite basis. Each satellite has one broadcast channel. The satellites which provide coverage to the continental U.S. had taskings for both broadcast channels. Eight channels were required to fill all required tasks. This is 400% of the total channel capacity. Two requirements were filled and left 6 requirements unsatisfied. The two satellites providing coverage to the Indian Ocean were able to cover all requirements with 1.5 broadcast channels. This correlates to 75% utilization. There were no communications requirements identified for the Atlantic and Pacific supporting satellites. [Ref. 4:p. 37]

Each UHF F/O satellite is equipped with seventeen, 25-kHz channels. Thus, two satellite coverage provides 34 such channels to each area of coverage. There was a 147% demand for 25-kHz channels on CONUS spacecraft. "Stage 1 uses all 34 on the CONUS satellites with sixteen network requirements left unsatisfied." [Ref. 4:p. 37] The satellites supporting the Atlantic footprint experienced a 29.4% utilization of their 25-kHz capacity while the Indian Ocean satellites experienced 70.6% of these same channels. The Pacific satellites 25-kHz channels were idle during this portion of the loading.

UHF F/O satellites have 21, 5-kHz channels. This infers that there are 42 channels available in each area of service. Only the CONUS spacecraft experienced any usage of these channels. Their total loading of 5-kHz channels was 14.3%.



Broadcast utilization %	100	0	75	0
25 kHz utilization %	100	29.4	70.6	0
5 kHz utilization %	14.3	0	0	0
Channels Needed	22	0	0	0

Figure 5.2. Stage 1 UHF Satellite Performance. After [Ref. 4:p. 36]

b. SHF Loading Performance

Figure 5.3 provides a summary of SHF satellite performance on a satellite by satellite basis. This proposed constellation of SHF satellites is able to meet all requirements. All units are covered by utilizing 2 of 3 spot beams on the Conus, Atlantic and Indian Ocean satellites. Only spot beams were used to provide service to all assets in each region. As stated in Chapter IV, EC beams were not employed in this loading. One of the two spacecraft over the Pacific is able to meet all requirements in that region with only one beam. The remaining IO spacecraft is idle.

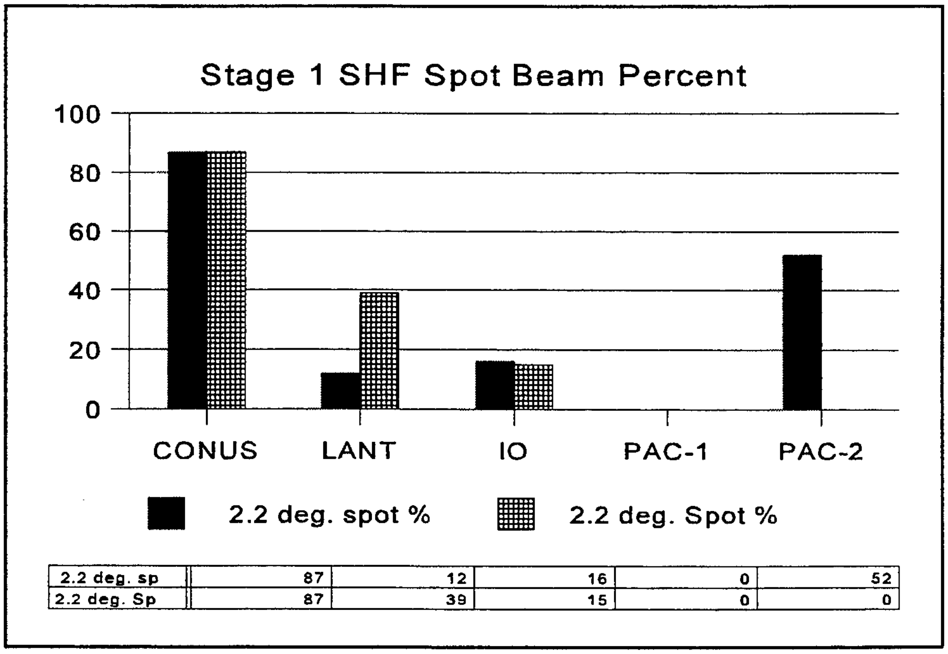


Figure 5.3. Stage 1 SHF Satellite Performance. After [Ref. 4:p. 37]

c. *Ka (GBS) Loading Performance*

The GBS payloads provided ample service for all currently defined requirements. "Regardless of scenario, there were few requirements in the draft FY 96 ERDB for the use of GBS."[Ref. 4:p. 39] Fleet wide implementation of GBS capabilities will burgeon future requirements for this systems. As afloat commanders come to realize the potential inherent to this system, they will demand greater access and additional services.

d. *A/EHF Loading Performance*

As previously mentioned, EHF loading was completed by utilizing MILSTAR spacecraft only. Figure 5.4 provides the loading requirements for each individual satellite. Only minimal loadings were experienced on these spacecraft. The highest percentage loading was for the Indian Ocean satellite which operated at 54% of its downlink capacity. The next

highest loaded spacecraft was the one supporting CONUS. It operated at 18% of its downlink capacity.

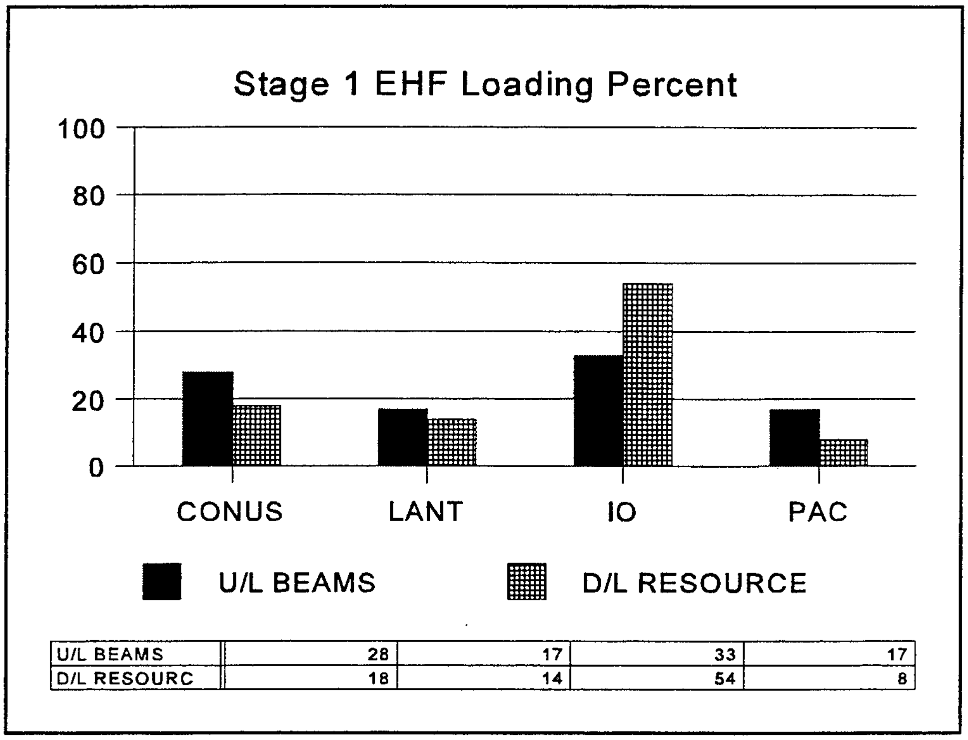


Figure 5.4. Stage 1 EHF Satellite Performance. After [Ref. 4:p. 40]

2. Stage 2 Loading Results

Stage 2 examines the satellite capabilities required by the force structure used to support the two LRCs examined in Stage 1, plus the additional capabilities required to support the Korea/China MRC. Figure 5.5 provides the overall loadings required to support all Stage 2 scenario operations. Additional subsections will examine each individual satellite genre and discuss specific satellite loadings.

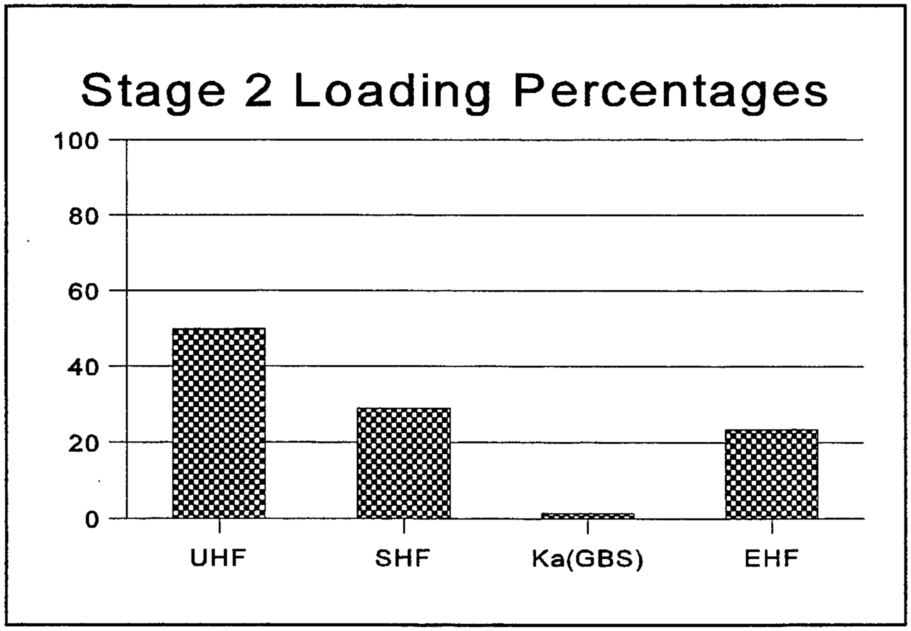
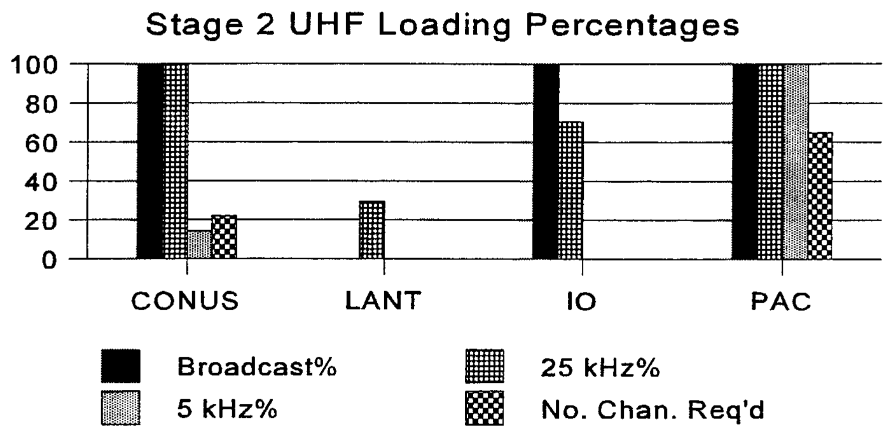


Figure 5.5. Stage 2 Naval Loading Percentages. After [Ref. 4:p. 40]

a. *Stage 2 UHF Loading Performance*

The introduction of an MRC to the existing scenario dramatically increases the usage of UHF assets. There is a 200% demand for broadcast channels and a 285% demand for 25-kHz service on PAC assets. "The MRC uses all of the PAC satellites and leaves two broadcast nets and sixty-three 25-kHz nets unsatisfied."[Ref. 4:p. 42] The IO spacecraft experienced a 25% increase in broadcast demand. All other UHF asset loadings were unaffected by the addition of the China/Korea MRC. Figure 5.6 provides the loadings for individual spacecraft.

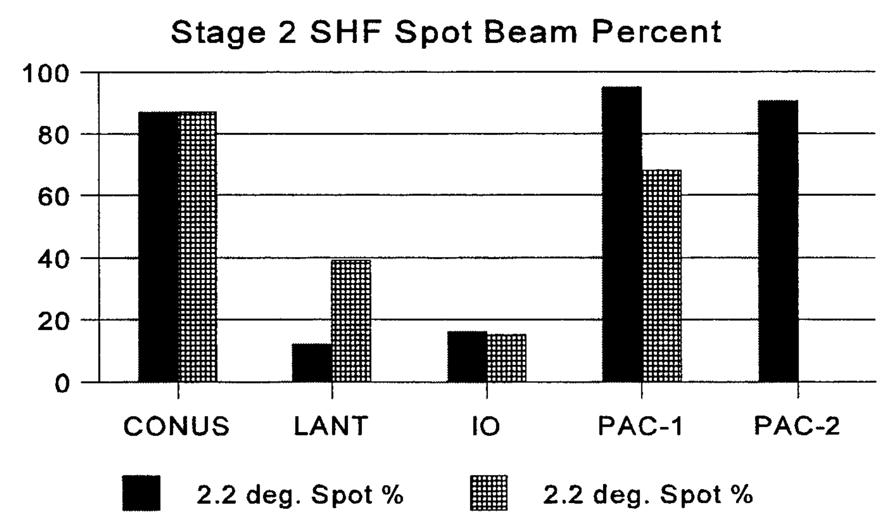


Broadcast%	100	0	100	100
25 kHz%	100	29.4	70.6	100
5 kHz%	14.3	0	0	100
No. Chan. Req'	22	0	0	65

Figure 5.6. Stage 2 UHF Satellite Performance. After [Ref. 4:p. 42]

b. Stage 2 SHF Loading Performance

SHF spacecraft were able to support all communication requirements throughout Stage 2. Figure 5.7 illustrates the loadings of the SHF constellation spacecraft. The addition of an MRC in the Pacific area of operations creates a significant increase in the bandwidth demand for supporting assets. There was a combined increase of 76.5% in demand placed on these satellites. An additional spot beam was added to cover all requirements. "Although the 2.2· spot beam 1 is used nearly to capacity on both the PAC satellites, the SHF constellation remains robust despite the severe stress of the scenario."[Ref. 4:p. 42]



2.2 deg. Sp	87	12	16	95	90.5
2.2 deg. Sp	87	39	15	67.8	0

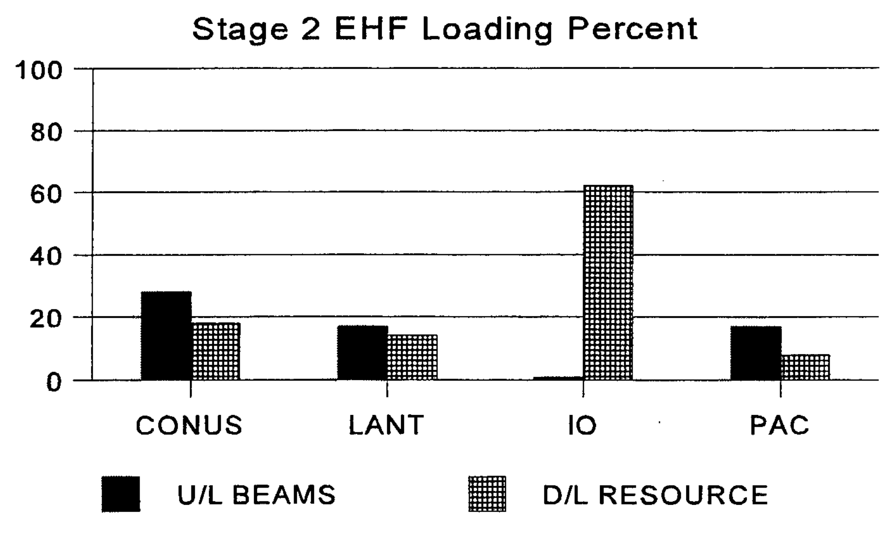
Figure 5.7. Stage 2 SHF Satellite Performance. After [Ref. 4:p. 42]

c. *Stage 2 Ka (GBS) Loading Performance*

The addition of an MRC increases the 0.5% GBS loading in Stage 1 to 1.4% in stage 2. "The real potential of this two-way wideband system is not fully realized in this scenario. The GBS requirements are covered by three beams using a 3.5 transponder." [Ref. 4:p. 434]

d. *Stage 2 A/EHF Loading Performance*

The 4 MILSTAR spacecraft are able to support all Naval EHF requirements in this scenario. "Despite the considerable stress added by the cumulative scenario requirements, the A/EHF capability remains robust without jamming during Stage 2." [Ref. 4:p. 44] Figure 5.8 displays the EHF performance for this scenario without jamming.



U/L BEAMS	28	17	1	17
D/L RESOURC	18	14	62	8

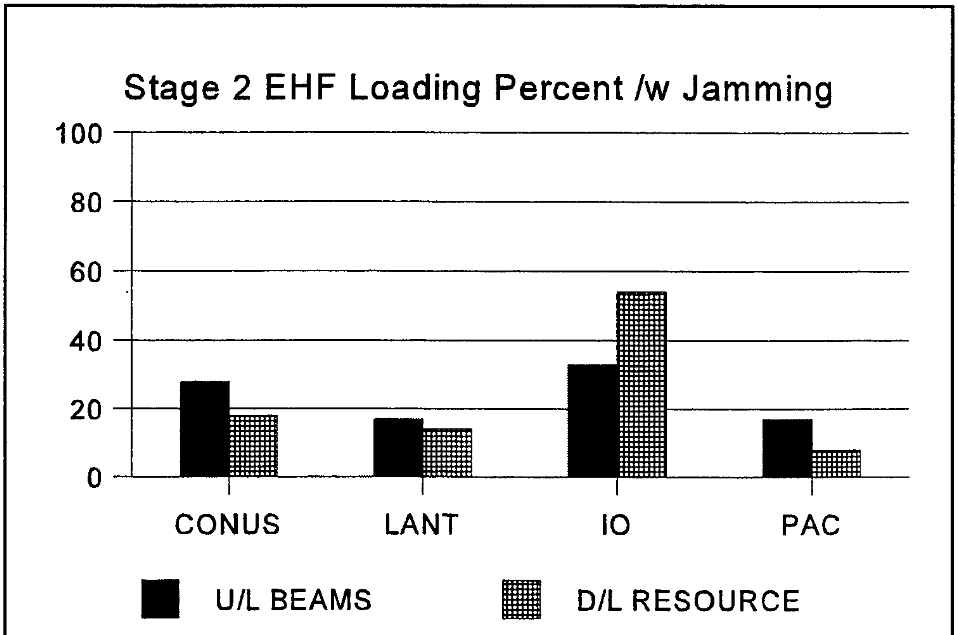
Figure 5.8. Stage 2 EHF Satellite Performance. After [Ref. 4:p. 44]

e. *Stage 2 A/EHF Loading Performance with Jamming*

MILSTAR spacecraft are touted as being resistant to jamming. A nuisance jammer was added in the MRC to analyze the performance of the A/EHF system in a jamming environment. So far as the analysis tools were able to determine, the jammer had little effect on the operation of the A/EHF system. Figure 5.9 illustrates the loadings placed on each spacecraft throughout the scenario.

Introduction of a wideband nuisance jammer in the MRC theater requires more resources than Figure 5.9 implies. Analysis reveals that there are specific instances were the jamming was effective, on platforms if not the spacecraft. Note that the Indian Ocean spacecraft appears to use fewer resources with jamming than without jamming. This is

because twelve submarines were unable to be included in 21 of the EHF networks. Since they are unable to close the link it appears that the jamming frees resources.[Ref. 4:p. 44]



U/L BEAMS	28	17	33	17
D/L RESOURC	18	14	54	8

Figure 5.9. Stage 2 EHF Satellite Performance with Jamming. After [Ref. 4:p. 45]

3. Stage 3 Loading Results

Stage 3 adds two additional LRCs to the scenario described in Stage 2. "The loading study examines the resources required for supporting a LRC in the Falkland Islands with a Joint Task Force Commander embarked, and a LRC in Somalia." [Ref. 4:p. 45] Figure 5.10 provides the loadings required to support scenario operations. Figure 5.10 still appears, at first glance, to be very encouraging. When considering the illustration scaling and lack of other loaded requirements, the results are not so encouraging. The UHF segment of the

architecture constitutes 60% of the total system capacity. This is only Naval requirements. Later sections will identify the detailed loadings for each genre of satellite.

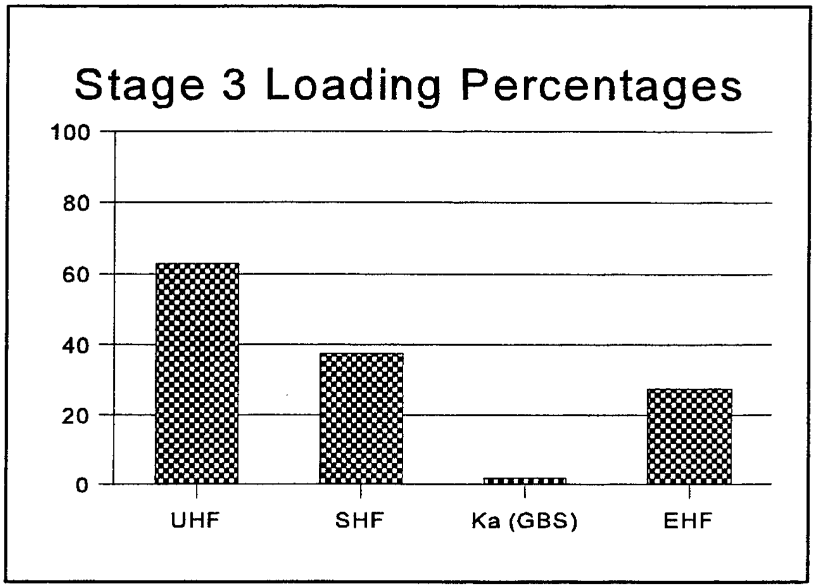
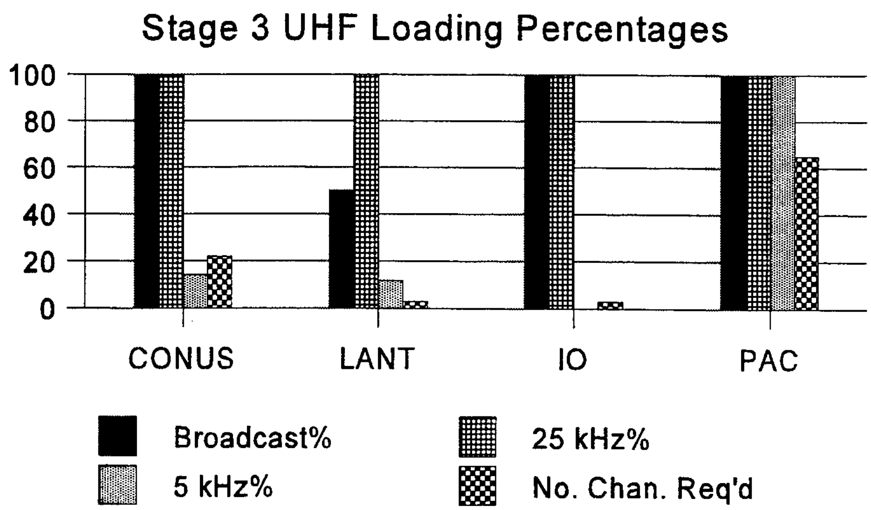


Figure 5.10. Stage 3 Loading Percentages. After [Ref. 4:p. 45]

a. Stage 3 UHF Loading Performance

The scenario in Stage 3 proved to be too extensive for the UHF constellation. "The UHF constellation is over subscribed in stage 3."[Ref. 4:p. 46] Figure 5.11 describes the total load placed on the system by the scenario. Broadcast requirements are for 200% of system capacity. There is a 168% demand for 25-kHz channels in this scenario. The system can support a maximum of 136, 25-kHz channels. 85 requirements for these channels were unsatisfied by the proposed architecture. The Pacific satellites also experienced 100% utilization of 5-kHz channels. 5-kHz channels were the least utilized of any UHF channel throughout the loading. 115 of these circuits went idle throughout the loading .

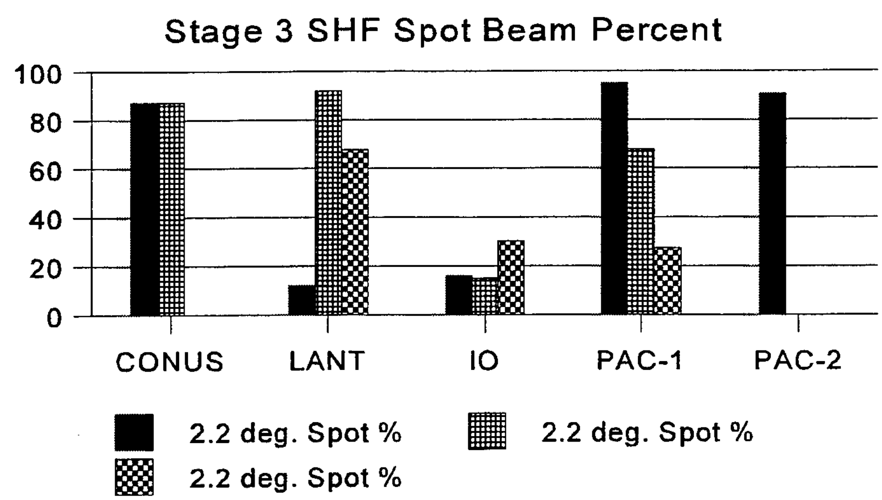


Broadcast%	100	50	100	100
25 kHz%	100	100	100	100
5 kHz%	14.3	11.9	0	100
No Chan. Req'	22	3	3	65

Figure 5.11. Stage 3 UHF Satellite Performance. After [Ref. 4:p. 47]

b. Stage 3 SHF Loading Performance

Figure 5.12 illustrates the SHF constellation loadings during the Stage 3 scenario. An additional Atlantic spot beam was utilized to provide coverage for the Falklands. The Indian Ocean spacecraft also used an additional spot beam to support operations in Somalia. The constellation fulfilled all Naval requirements throughout all three stages of the loading.



2.2 deg. Sp	87	12	16	95	90.5
2.2 deg. Sp	87	92	15	67.8	0
2.2 deg. Sp		67.8	30.1	27.3	

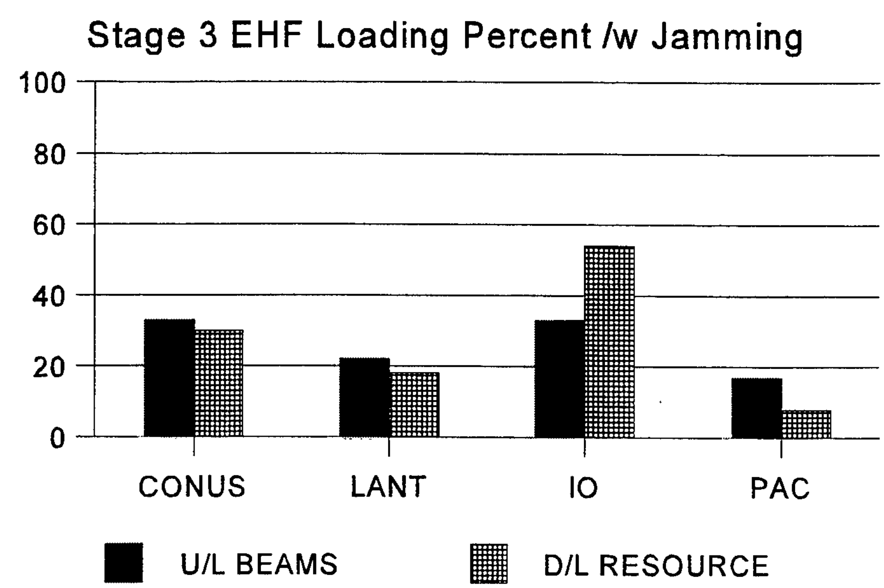
Figure 5.12. Stage 3 SHF Satellite Performance. After [Ref. 4:p. 47]

c. *Stage 3 Ka (GBS) Loading Performance*

The Global Broadcast System remained underutilized throughout the scenario buildup. Stage 3 loading required only 1.84% of total system capacity.

d. *Stage 3 A/EHF Loading Performance with Jamming*

Stage 3 loading considered only the situation with an operational nuisance jammer. Figure 5.13 describes the loadings on each of the MILSTAR satellites. "Figure 5.13 also illustrates an increase of nearly double the resources used on the CONUS EHF satellite during the Falkland Islands LRC." [Ref. 4:p. 48] The A/EHF constellation fulfilled all Naval requirements throughout all stages of the loading scenario.



U/L BEAMS	33	22	33	17
D/L RESOURC	30	18	54	8

Figure 5.13. Stage 3 EHF Satellite Performance with Jamming. After [Ref. 4:p. 49]

VI. CONCLUSIONS AND RECOMMENDATIONS

A. LOADING CRITIQUE

The Booz-Allen & Hamilton (BAH) loading analysis provides a basic metric for identifying shortfalls associated with the proposed MILSATCOM architecture. This is of great interest to the U.S. Navy when considering the importance this architecture will play in future Naval operations. The study is, however, limited in that it only considers Naval requirements and current military tactics.

1. Total Requirements

As previously stated in Chapter V, Naval requirements constitute only a small percentage of the overall MILSATCOM communication requirements. The ERDB formed the basis for the loading. It is the tool by which the Navy predicts future requirements for both the Navy and Marine corps. It does not address future requirements or growth rates of other services or government agencies. The study, by not specifically addressing these issues, cannot make any predictions as to the percentage of capacity which will be demanded by each of the entities in the future. It is possible that one or more of the other entities dependent on the architecture, such as the Army or Air Force, could have a greater growth in requirements than the Navy. This would lead to that service's assigned bandwidth percentage out-weighing that allotted to the Navy. Considering the conduct of the loading analysis, it will provide no indication of an impending traffic overload situation. By limiting the study to Naval requirements, the loading analysis results provide only a crude estimation as to areas of bandwidth capacity shortfall and the extent to which the SATCOM system will be

oversubscribed.

2. Revolution in Military Tactics

There is an ongoing revolution in tactics employed by the U.S. armed forces. The development of new tactics and force employment methods has been fueled by growth in information technology. This technology is an enabler which allows smaller, more mobile forces to overcome numerically superior forces. Information technology has been a key in the development of new 'smart weapons' and more capable command and control systems. The BAH study did not examine the impact new tactics and weapons systems would have on the MILSATCOM architecture. It predicted future usage requirements based on extrapolation of current force structure and tactics. This MILSATCOM architecture is to be implemented in the year 2008. At that date, the U.S. military will operate under a different force structure and tactics than envisioned in the BAH study, which will have a marked effect on predicted SATCOM requirements. The remainder of this section will identify emerging tactics and systems which might alter the requirements used as a baseline for the MILSATCOM loading analysis.

a. Revolution in Naval Surface Fire Support

Naval Surface Fire Support (NSFS) is the means by which the surface navy supports and enables Marine Corps assault and maneuver in the littoral environment. Current shipboard gun systems are range limited to 13 nautical miles.[Ref. 25:p. 26] This range is well within the limits of terrestrial line-of-sight communications systems. Gun system research is fast changing this. The new 5-inch/62-caliber gun will be introduced into the fleet in the year

2000. This gun will have a maximum range of approximately 70 nautical miles. The Vertical Gun for Advanced Ships (VGAS) is expected to be fielded in 2010. This is a vertically fired, rocket assisted 155 mm gun system capable of a maximum range of 100 nautical miles. Both of these systems will support maneuver far in excess of line-of-sight communications.[Ref. 25:p. 27] This increased fire support range will demand SATCOM resources for spotting and call for fire functions. Ground forces will require over- the-horizon links with fire support ships for fire adjustment and safety calls. This development, which was not considered by the study, will produce new requirements which must be fulfilled by the supporting MILSATCOM architecture.

b. Tactical Aircraft SATCOM

Both the Navy and Air Force have stated a goal of placing voice SATCOM systems on future fighter aircraft. The Air Force intends to place EHF communications systems aboard its tactical aircraft. The Navy intends to use UHF SATCOM for its fighter links. The Joint Strike Fighter, scheduled for introduction in the early part of the next century, will be the first U.S. tactical aircraft initially designed with a voice SATCOM system. All of these developments were neglected in the loading analysis. UHF and EHF SATCOM systems in Navy and Air Force aircraft will create a need for many channels. Based on the UHF loading results, it would appear that Navy tactical aircraft, with UHF SATCOM, alone could overload the system in one geographical region.[Ref. 26]

c. *Coalition Warfare*

Warfare in the future will be fought by coalitions. Operation Desert Storm was one example of a coalition of military forces acting in concert to achieve a common goal. The escalating cost of modern warfare will necessitate this type of cost and risk sharing in the future. The threat of fratricide requires that all coalition partners have effective communications with each other. U.S. forces, in the past, have provided its partners with some SATCOM capabilities to limit the possibility of 'blue-on-blue' engagements. The Booz-Allen study did not incorporate this scenario into their analysis. Sharing bandwidth with partners is necessary and proper, but limits the bandwidth available to U.S. users.

d. *Marine Corps Hunter Warrior Concept*

The Marine Corps is investigating new tactics to capitalize on information systems. One of these tactical concepts is the Hunter-Warrior concept. This is a break from traditional Marine tactics. Normally Marines fight on a company level. The Hunter-Warrior concept has small groups of Marines operating over vast areas of land to harass and interdict the enemy. Normally groups would consist of 3 or 4 Marines. They rely on information superiority and maneuver to ensure their effectiveness and survival. Although HF skywave and meteor burst systems can provide beyond-line-of-sight communications, they are inferior to SATCOM systems in terms of providing Hunter-Warrior teams with secure, timely, compact communications at sufficient data rates. This will create a large demand for SATCOM access. It was not addressed in the Booz-Allen study and could have a profound effect on overall Naval communication requirements.[Ref. 27:p. 12]

B. RESEARCH ANALYSIS

Three fundamental questions regarding the MILSATCOM architecture were identified in Chapter One of this document. Deficiencies have been noted with the scope of the loading analysis. Focus throughout the conduct of this research has been concentrated on developing answers for these questions within the defined scope. Findings and conclusions reached as a result of the research performed are expressed in the remainder of this section.

1. Question One

Does the MILSATCOM architecture meet Naval communications requirements as defined in the ICDB and the ERDB?

Stage 1 loading results provide the answer to this question. The CONUS spacecraft of the UHF constellation were oversubscribed when the system was loaded for normal background operations and two LRCs. As the loadings increased in complexity, more shortfalls in the total capacity of the architecture became apparent. As a result, it is logical to assert that specific segments of the proposed MILSATCOM architecture do not meet all Naval requirements.

2. Question Two

What are the specific system shortfalls if the architecture does not meet all defined requirements?

There were requirements shortfalls identified throughout each stage of the loading analysis. Not all shortfalls identified, however, were associated with each class of satellite. At least one class of satellite had no significant shortfalls noted. For this reason, findings of

system shortfalls will be listed by satellite class.

a. *UHF Loading Findings*

UHF satellites demonstrated the most acute limitations of all systems analyzed throughout the loading. UHF assets were not capable of satisfying 100% of Naval requirements in any of the test scenarios. It is important also to restate that the loadings did not consider any requirements from other services or government agencies. With only a fraction of the actual operational requirements loaded, the system was heavily oversubscribed. This realization provides a framework to better understand the extreme limitations associated with this segment of the architecture.

UHF communications have proven to be the backbone of Naval SATCOM for the past several decades. Shortcomings in this band could have a dramatic impact on mobile users throughout the Naval service. 25-kHz circuits are identified by the loading as the most heavily impacted of the UHF channels. The loading identified 85 UHF 25-kHz requirements that were unfulfilled.[Ref. 4:p. 45] The proposed 8-satellite constellation of UHF spacecraft does not provide the communications capacity necessary to support Naval users in the operational environment of the future.

b. *SHF Loading Findings*

The SHF constellation met all Naval requirements in each of the loading stages. Stage 3 loadings placed the greatest stress on the SHF constellation. Naval requirements for this stage constituted approximately 40% of the total system capacity.[Ref. 4:p. 45] It is important to note, again, that the loading analysis neglected other service or

government agency SHF requirements. It is unrealistic to believe all other U.S. requirements will be satisfied by the remaining 60% of the system capacity. In real-world situations it is conceivable that some Naval requirements would go unfulfilled due to higher level requirements from other user segments. Augmentation for SHF capabilities might be required to satisfy 100% of future requirements.

c. *Ka (GBS) Loading Findings*

The GBS segment of the architecture met all Naval requirements throughout each stage of the loading. Stage 3 of the loading placed the greatest amount of stress on the system. With one MRC and four LRCs included in the scenario, maximum system usage was 1.84%.[Ref. 4:p. 45] One reason for the minimal usage on the GBS system is that "there were few requirements in the draft FY 96 ERDB for use of the GBS."[Ref. 4:p. 39]

d. *A/EHF Loading Findings*

The A/EHF MILSTAR constellation fulfilled all Naval requirements throughout the loading analysis. System usage during Stage 3 only reached 27% of total system capacity.[Ref. 4:p.45] The loading also omitted the EHF packages aboard UHF spacecraft. Considering the total capacity of the MILSTAR system and the buffer capacity carried aboard UHF spacecraft, it appears that the EHF constellation is fully capable of meeting its future requirements. The system will still require periodic monitoring to prevent 'requirement creep' or slowly increasing requirements over the years which will ultimately diminish is utility.

3. Question Three

Once shortfalls have been identified, what can be done to fulfill them?

This research has considered both proven and emerging technologies which have potential to provide augmentation for systems with requirements shortfalls. This section identifies specific system alternatives and identifies the shortfalls which they are to address.

a. DAMA Implementation

The implementation of DAMA in UHF networks increases system efficiency by allowing greater numbers of users to access the same circuit. Introduction of DAMA will satisfy a greater number of requirements than the standard duplex communication systems.

b. Re-evaluation of Voice Data Rate Requirements

All voice requirements in the 1996 ERDB are greater than 2.4 kbps.[Ref. 4:p. 50] This is a result of a trend in modern communication systems which strives for greater voice quality. A communication paradigm which is relevant to this situation is that digital transmissions providing greater voice clarity also require more bandwidth. Field commanders have identified a need for voice recognition. Many of the command and control functions in modern warfare are carried out by voice circuits on the battle field. Commanders feel that a better understanding of a specific situation may be attained by being able to hear 'how' combatants say something and not just 'what' they say.[Ref. 19:p. 4-38]

The U.S. military has operated successfully for years with 2.4 kbps voice networks. It is understandable that commanders would desire voice recognition on certain circuits. This capability would provide them with more insight to an operational situation.

The question is however: Do all voice networks require 4.8 kbps or greater data rates? Some of the newly emerging commercial SATCOM systems such as IRIDIUM and GLOBALSTAR offer voice services at 2.4 kbps.[Ref. 28:p. 1] If these new systems are able to compete for market share in the competitive Personal Communication System (PCS) market, then surely there are some military networks which could operate effectively at 2.4 kbps. More 25-kHz circuits would be available for other network requirements if non-vital networks were migrated to 2.4 kbps circuits.

c. *Commercial Satellite Service Providers*

Commercial satellite service providers are capable of augmenting point-to-point communications required by the proposed architecture. Emerging mobile satellite providers have concentrated their development efforts on the point-to-point PCS markets. This augmentation could ease some of the overloading on UHF satellites by diverting some voice requirements. Generally, commercial providers do not offer the netted services which could augment netted circuit requirements identified in the ERDB.[Ref. 28:p. 1]

The IRIDIUM system is one example of a large commercial PCS system which is capable of fulfilling some Naval MILSATCOM requirements. The constellation consists of 66 satellites in LEO. The inclination of the orbital planes provides the system with world-wide coverage. This aspect of the system satisfies Naval requirements for polar coverage which are left unfulfilled by the DoD-owned GEO systems.

Limitations associated with IRIDIUM are similar to those of other commercial systems. Primarily, the government does not own the system and, therefore, does not control

it. Service could be cut off by the service provider. Survivability of the system is also an issue. Military systems are designed to be robust and have a long operational life. Commercial systems are engineered for shorter life spans which allow providers to upgrade system technology and remain competitive in their market. This philosophy works well in the commercial arena, but has definite limitations in military applications. Since they are not as robustly engineered as the military spacecraft, commercial spacecraft become more vulnerable to exploitation or attack by an adversary. Industry will tolerate minor coverage gaps while replacing a damaged satellite, but this gap in coverage might prove crucial to military users.

The capacity of IRIDIUM is the most significant limitation of the system. Each satellite has an 1,100 channel capacity. These channels are distributed among 48 spot beams. This configuration provides approximately 30 channels to each footprint. A typical spot beam will have a diameter of 600 km.[Ref. 28:p. 1] The system will employ Time Division Multiple Access (TDMA) for access in each footprint. It also uses Frequency Division Multiple Access (FDMA) to enhance system performance by allowing frequency reuse between spot beams.[Ref. 29:p. 1] Since there are few channels (approximately 30) available in any footprint, military users might be forced to compete with commercial users for access to the system. An adversary could overload the system with a few commercially available handsets. In times of high traffic, military users alone could cause an overload on the system.

The loading analysis identified 111 point-to-point requirements which could be satisfied by commercial mobile service providers. Migrating some of the less critical requirements to commercial systems would open more 25-kHz channels to operational

users.[Ref. 4:p. 50]

d. *Consideration of EHF*

The A/EHF constellation met all requirements during the loading. In fact, the MILSTAR system was not heavily loaded, and the surge capacity of the UHF packages was not even considered. Consideration should be given to migrating some UHF network requirements to EHF. Each UHF satellite EHF package is equipped with 3 broadcast and 7 uplink communication channels.[Ref. 5:p. 4-66] Some of the required circuits could be loaded on the UHF satellite EHF package. This would reduce the loading on the UHF circuits and not significantly impact the loading on MILSTAR spacecraft.

e. *GBS Applications*

As noted on the SHF loadings, there are some requirements which were filled in this loading but would probably go unfulfilled in real-world situations. SHF systems are primarily used for wideband services. The GBS system was designed to provide a one-way wideband broadcast of information to deployed units. Some less critical SHF requirements might be transitioned to the GBS system. This would reduce Naval loadings on the system and allow more usage of GBS assets. Users could apply the 'user pull' concept, in which existing narrowband communications channels are employed to request wideband information via the GBS system. There are already requirements for narrowband channels which could provide the conduit for users to request non-sensitive wideband data via Global Broadcast dissemination. This could also serve as a boon to such emerging concepts as tele-medicine and conference calling. The video transmission would have to be one way, but it would

provide the service without impacting other systems.

f. Unmanned Aerial Vehicles (UAV)

Unmanned Aerial Vehicles (UAVs) are a non-space based alternative to a regional communication overload. A squadron of UAVs equipped with communications relay packages can serve as an augmentation to satellite assets in a specific theater. They can operate for extended periods of time and do not require a pilot onboard for operation. A pilotless vehicle eliminates the threat of a downed airman in hostile territory. It also increases the availability of the system by terminating crew rest and other such requirements. A squadron of UAVs could operate around the clock and be outfitted with the communications package for which there is the greatest demand. This package could be changed while rotating UAVs are on-station in order to meet changing communication requirements in the region.

One limitation to the utility of UAVs is that they possess a small footprint. Some are capable of conducting operations at 50,000 feet. This sounds high but in reality it is very low when compared to a LEO satellite operating at an altitude of 1,000 km. The lower altitude of a UAV infers that it will have a much smaller footprint than a spacecraft operating on the same frequency. With a smaller footprint, UAVs would be forced to operate closer to front line units, and thus become a viable target for an adversary. Special consideration would have to be given to air defense in offering protection for these assets.

g. *Aerostats*

Aerostats or 'blimps' are being developed as a means of providing commercial mobile communication services to a specific geographic area. These craft are unmanned and will maintain an altitude of 20 to 30 km. This will enable each craft to provide service throughout a 900 km diameter footprint. SKY STATION will be one of the first aerostat firms to provide service. The company plans to begin operations in 1998. They advertise an operational life of 10 years per aerostat. Each aerostat will be equipped with a proprietary navigation and control system. The 'blimp' will maintain its position above the earth through the use of its navigation system and will not be tethered to the ground. Once on station, the craft will provide service to both mobile and fixed user sites within its footprint. Mobile services will be provided at data rates between 64 kbps and 2.048 Mbps. Terminal size is the determining factor for mobile user data rates. A 5-foot dish is required for 2.048 Mbps transmissions. Fixed users will receive higher data rates. SKY STATION advertises a 155 Mbps data rate to fixed sites.[Ref. 30:p. 1]

The military could benefit by leasing or developing its own such program. This system would provide a large communications augmentation capability in a regional conflict. It could be utilized, like the UAVs, to supplement any system which is overloaded. SKY STATION has not released any firm cost estimates, but projects usage fees will approximate the cost of a standard long distance phone call. Difficulties associated with this system might involve interoperability with existing terminals. Safety of flight is an issue which also might require study. Air defense for the aerostat would have to addressed in regional tactics.

h. Challenge Athena

One concept which may aid in reducing the wideband loading on DSCS spacecraft is a Navy developmental project. It is called Challenge Athena. This project leases transponders from commercial providers in order to afford the fleet with more wideband capacity. INTELSAT is the company which is currently being utilized. This system uses the commercial transponder to provide 1.544 Mbps duplex communications to its users. Challenge Athena was not loaded into the scenario because it is not a military-owned system. This concept has the potential to significantly reduce the loading on wideband spacecraft by providing an alternative means of transmission for non-sensitive data.

C. RECOMMENDATIONS FOR FUTURE STUDY

By evaluating the solutions to the research questions and analysis shortfalls contained in this thesis, it is possible to identify certain topics which warrant future study. The remainder of this section covers possible topics for future thesis research.

1. Realistic Loading Analysis

Study of the constraints used in the conduct of the loading analysis indicates shortfalls in the analysis results. Limiting the study to Naval-only requirements, and the assumed use of current force structure and tactics, produced only tentative results. A full loading analysis which considers emerging tactics in concert with currently defined emerging requirements would provide a much greater insight to the degree which the proposed architecture will meet future national needs.

2. Requirements Re-evaluation

Several alternatives for loading shortfalls identified re-evaluation of stated requirements as a key to fulfilling Naval requirements. Future studies should focus on specific shortfalls identified in the loading analysis.

a. Narrowband Requirements

Narrowband requirements in the ERDB should be individually re-evaluated. Specific attention should be paid to bandwidth required, protection, coverage, topology and quality. Once these attributes have been isolated, a determination can be made as to whether or not the requirement was properly defined. Improper requirements should be redefined to better capture the need expressed by users, as compared to services available. Options for redefinition should include: realistic data rate, migration to EHF, migration to a commercial provider, and non-space based alternatives.

b. Wideband Requirements

Wideband requirements should be individually re-evaluated. Again, characteristics such as data rate, quality, coverage, topology and protection should be considered. Once this has been completed, the study should perform an analysis to identify requirements which could be better fulfilled by other means. Options for redefinition should include, but are not limited to, a migration to GBS, commercial providers, and non-space based systems.

3. Non-Space Based Augmentation of Satellite Capacity

Newly emerging technology is providing non-space based communications systems which are capable of providing augmentation for existing satellite systems during regional crises. The use of UAVs and other systems such as SKY STATION should form the basis for the study. The investigation should be conducted to determine the feasibility of these systems as an augmentation capability. Total capacity and services provided by each system should be examined. Cost benefit analysis of services available should be addressed. Logistics associated with each system should be identified. Timeliness and ease of relocation for each system should be addressed. SKY STATION is designed to maintain station on a specific area. Is it capable of moving, and how long will it take to move are questions which should be answered.

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